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THESIS

AN ANALYSIS OF WARFIGHTER SLEEP, FATIGUE, AND PERFORMANCE ON THE USS NIMITZ

by

Kevin M. Kerno

September 2014

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In an effort to inform Navy leaders of the potential effects of the ever increasing demands placed on enlisted sailors and officers, this thesis explores the sleep, fatigue, performance, and work schedules of the crew aboard the USS *Nimitz* (CVN-68). This research used actigraphy, self-reported sleep, and survey and questionnaire data to determine the amount of sleep that participants received and to assess whether differences existed between various groups, departments, and watch rotations. The Sleep, Activity, Fatigue, and Task Effectiveness Model-Fatigue Avoidance Scheduling Tool was used to predict the on-watch effectiveness of the participants. This research also sought to determine if the Navy standard workweek (NSWW) is an accurate tool for determining manning levels on U.S. aircraft carriers. The results showed that sailors and officers experienced severe to moderate sleep debt, often stood watch with low predicted effectiveness levels, and experienced high levels of daytime sleepiness. This study suggests that the NSWW should be updated and supplemented with a more robust tool for informing manpower decisions. Key differences in daytime sleepiness, diurnal preference, average daily sleep, and on-watch predicted effectiveness levels were found between the various groups, departments, and watch rotations analyzed in this study.

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LIST OF ACRONYMS AND ABBREVIATIONS

AFRL	Air Force Research Laboratory
AOR	area of responsibility
ARL	U.S. Army Research Laboratory
ARLHSRED	U.S. Army Research Laboratory Human Research & Engineering Directorate
ASP	average sleep propensity
AURA	Army Unit Resilience Analysis
BAC	blood alcohol content
CNA	Center for Naval Analyses
CAS	circadian alertness simulator
CCG	carrier group
CDR	commander
CIC	Combat Information Center
CNO	Chief of Naval Operations
COMNAVSURFOR	Commander, Naval Surface Forces
CRSD	circadian rhythm disorder
CSM	Composite Scale of Morningness
CSV	comma separated values
CVN	carrier vertical nuclear
DOD	Department of Defense
DOE	design of experiments
DTS	Diurnal-Type Scale
EEG	electroencephalographic
ESS	Epworth Sleepiness Scale
FAA	Federal Aviation Administration
FAID	fatigue audit interDyne
FRA	Federal Railroad Association
FAST	Fatigue Avoidance Scheduling Tool
GUI	graphical user interface
HSI	human systems integration

IBR	Institutes for Behavior Resources
ICSD-2	International Classification of Sleep Disorders-2
ID	Identification Number
IMPRINT	Improved Performance Research Integration Tool
JOOD	junior officer of the deck
JOOW	junior officer of the watch
JTFEX	joint task force exercise
LCDR	lieutenant commander
LCS	littoral combat ship
LT	lieutenant
MANPRINT	manpower and personnel integration
MEQ	Morningness-Eveningness Questionnaire
MRMC	Medical Research and Materiel Command
MSLT	Multiple Sleep Latency Test
NASA	National Aeronautics and Space Administration
NHRC	Naval Health Research Center
NPS	Naval Postgraduate School
NREM	non-rapid eye movement
NSF	National Sleep Foundation
NSWW	Navy standard workweek
OECD	Organization for Economic Cooperation and Development
OEF	Operation Enduring Freedom
OOD	officer of the deck
OSPC	operational strike planning cell
PORV	pilot-operated relief valve
PSG	polysomnography
PSQI	Pittsburgh Sleep Quality Index
PVT	psychomotor vigilance task
Q-Q	Quantile-Quantile
REM	rapid eye movement
RT	response time
S-3	Sea Control-3

SAFTE	Sleep, Activity, Fatigue, and Task Effectiveness Model
SAIC	Scientific Applications International Corporation
SCN	suprachiasmatic nucleus
SPM	sleep and performance model
SUSTEX	sustainment exercise
SWD	shiftwork disorder
USAARL	U.S. Army Aviation Research Laboratory
USAF	United States Air Force
USB	universal serial bus
VBA	Visual Basic for Applications
VTS	vessel traffic service
WAM	wrist activity monitor
WESTPAC	Western Pacific
WHO	World Health Organization
WRAIR	Walter Reed Army Institute of Research

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EXECUTIVE SUMMARY

U.S. Navy sailors and officers are exposed to a myriad of dangers every day, both while deployed and in port. Their jobs are inherently dangerous, and this danger cannot be avoided. U.S. Navy personnel must perform challenging tasks under pressure and with little or no room for error. They are called upon to do these tasks day-in and day-out, 24 hours a day, 365 days a year, in some of the harshest environments imaginable. Mistakes occur as a result of these high-stakes and high-risk evolutions, but some of these mistakes could be avoided.

Due to the requirement of U.S. Navy warships to operate 24 hours a day while operationally deployed, the crew performs its duties while operating in a shiftwork environment. Even more challenging is when these shifts are continually rotating, which causes the crew to sleep at different times each day and adapt to a constantly changing schedule. Unfortunately, this rotational work routine greatly disrupts enlisted sailors' and officers' sleep cycles and circadian rhythms. Thus, while performing extremely dangerous and challenging missions of tremendous national and global importance, many U.S. Navy sailors and officers are doing so in an environment that leaves them clinically and critically sleep deprived. The consequences of sleep deprivation and fatigue can be disastrous, as demonstrated by the accidents at Chernobyl Reactor 4, Three Mile Island Unit 2, Bhopal Union Carbide, and the *Exxon Valdez* oil spill (Chiles, 2002). The U.S. Navy is certainly not immune to similar types of incidents.

Aircraft carriers are considered one of the U.S. Navy's most important assets and are absolutely crucial for meeting U.S. maritime strategic policy objectives. The increased operational tempo and duration of deployments for aircraft carriers places additional responsibilities and demands upon officers and enlisted crewmembers. Furthermore, modern military vessels are becoming more technologically advanced while manning levels are being reduced, thus requiring sailors to process more information and maintain alertness and vigilance for

longer periods of time. Yet, the watch rotations and work schedules still being used are those that prevent sailors from operating at or near peak performance.

Fortunately, the U.S. Navy's leadership is beginning to recognize that forcing sailors and officers to maintain traditional watch rotations and schedules that fail to account for human circadian rhythm and sleep patterns is not optimal for preserving and strengthening a powerful naval war-fighting force. Thus, steps are being taken to realign traditional thinking in regards to sleep, fatigue, and schedules throughout the U.S. Navy. In May 2013, the Commander, Naval Surface Forces (COMNAVSURFOR) issued a message discussing the revision of watch rotation requirements and daily routines in order to maximize the effectiveness of watchstanders. COMNAVSURFOR recognized that while the Navy invests a tremendous amount of time and effort in maintaining equipment, not enough time and effort is invested in "the health, well-being, and safety of our sailors" (Commander, Naval Surface Forces [COMNAVSURFOR], 2013, p. 1). The COMNAVSURFOR message also discusses the importance of adopting a watch rotation that is in-line with the human circadian rhythm, which has been widely ignored on operational vessels. Clearly, sleep and fatigue are being taken more seriously by U.S. Navy leaders.

Yet, facilitating the changes in watch rotations and schedules that are necessary for maintaining a well-performing naval force cannot be instituted without addressing the method by which the U.S. Navy determines required manning levels for ships. In order to determine the personnel assigned to each class of ship, the Navy designed, and still utilizes, a standardized version of one week of activity performed while at sea. This standard week is referred to as the Navy standard workweek (NSWW). The NSWW designates 81 hours per week for available time or on-duty time and 87 hours per week for non-available time (time for sleeping, messing, personal time, etc.) in determining manning for all ships. Past studies at the Naval Postgraduate School (NPS) have shown, however, that most personnel are sleeping less and working more than set forth in the NSWW (Green, 2009; Haynes, 2007; Mason, 2009). Clearly, there is a

disconnection between the method for determining manning levels on ships and the actual daily requirements placed upon sailors. This disconnect must be addressed in order to effectively manage sailors' work, sleep, and fatigue levels.

Very limited sleep and fatigue research studies have been conducted on aircraft carriers. This thesis statistically analyzed the sleep, fatigue, performance, and work schedules of sailors and officers aboard the USS *Nimitz* (CVN-68) through the use of actigraphy data, sleep and activity logs, and the Sleep, Activity, Fatigue, and Task Effectiveness Model-Fatigue Avoidance Scheduling Tool (SAFTE-FAST) (Institutes for Behavior Resources [IBR] Inc., 2014). It also compared the NSWW to the actual daily requirements placed upon sailors and officers to assist in determining if the NSWW is an adequate tool for establishing aircraft carrier manning levels.

Results of this research showed that sailors experienced severe to moderate sleep debt, often stood watch with low predicted effectiveness levels, experienced high levels of daytime sleepiness, and that the NSWW does not accurately reflect the daily work schedules of most enlisted sailors and officers on U.S. aircraft carriers. Key differences in daytime sleepiness, diurnal preference, average daily sleep, and on-watch predicted effectiveness levels were found between the various groups, departments, and watch rotations analyzed in this study.

The results of this thesis have potential implications for the U.S. Navy. First, watch rotations currently being used result in significant sleep debt and poor on-watch performance. Thus, alternative watch rotations that take into account the effect of circadian rhythms must be implemented. Second, the myriad of tools available to operational units for assessing sleep, fatigue, and performance while at sea are underutilized even though the cost to implement them would be minimal and pose little burden to personnel. SAFTE-FAST and other sleep and fatigue analysis and diagnostic tools such as the Epworth Sleepiness Scale (ESS), which is used to measure a person's daytime sleepiness, and the Composite Scale of Morningness (CSM), a method for

determining a person's diurnal preference, should be used in the development of watch rotations and work schedules and for identifying potentially sleep deprived and overly fatigued individuals. Doing so could help prevent mistakes and mishaps that often lead to costly damage and personnel injury. Third, the NSWW does not accurately reflect the daily work schedules and demands placed upon enlisted sailors and officers. In order to better inform manpower decisions and planning, the NSWW must be updated and supplemented with other robust tools, such as Improved Performance Research Integration Tool (IMPRINT) Pro, a dynamic, stochastic discrete event simulation tool capable of analyzing manpower and human-system interaction problems in order to more effectively allocate personnel to operational units (Alion Science and Technology, 2014; U.S. Army Research Laboratory, Human Research & Engineering Directorate [ARLHSRED], 2010).

The data analyzed in this thesis is observational and not the result of a designed experiment. Additionally, the sample of participants in this research may not be representative of the entire population of personnel serving on U.S. aircraft carriers or in the U.S. Navy. A generalization of the initial findings of this study to the entire U.S. Navy or all aircraft carriers should not necessarily be made based on the results of this thesis.

The results of this thesis illustrate a need for additional research in a number of areas. Larger studies encompassing multiple naval platforms and operational units should be conducted in order to determine the generalizability of the ESS, CSM, and SAFTE-FAST results found in this study. Furthermore, additional studies are needed in order to validate a maritime version of SAFTE-FAST. Additional and more detailed studies that collect sleep, work, and other activity data of entire ships' crews must be conducted in order to update the NSWW and serve as input into more robust manpower modeling tools, such as the IMPRINT Pro Forces Module.

LIST OF REFERENCES

Alion Science and Technology. (2014, April). IMPRINT Pro training and user meeting. Presented at Aberdeen Proving Grounds, Aberdeen, MD.

Chiles, J. R. (2002). *Inviting disaster: Lessons from the edge of technology an inside look at catastrophes and why they happen*. New York, NY: HarperCollins Publishers, Inc.

Commander, Naval Surface Forces. (2013). *Circadian Watchbill* [Official U.S. Naval message]. DTG 032157Z May 13. San Diego, CA.

Green, K. Y. (2009). *A comparative analysis between the navy standard workweek and the actual work/rest patterns of sailors aboard U.S. Navy frigates* (master's thesis. Retrieved from Calhoun http://hdl.handle.net/10945/4434

Haynes, L. E. (2007). *A comparison between the Navy standard workweek and the actual work and rest patterns of U.S. Navy sailors* (master's thesis). Retrieved from Calhoun http://hdl.handle.net/10945/3298

Institutes for Behavior Resources, Inc. (2014). *SAFTE-FAST: Fatigue modeling for fatigue risk management*. Baltimore, MD: Institutes for Behavior Resources, Inc.

Mason, D. R. (2009). *A comparative analysis between the Navy standard workweek and the work/rest patterns of sailors aboard U.S. Navy cruisers* (master's thesis). Retrieved from Calhoun http://hdl.handle.net/ 10945/4541

U.S. Army Research Laboratory, Human Systems Research and Engineering Directorate. (2010). *Improve Performance Research Integration Tool*. Retrieved from http://www.arl.army.mil/www/default. cfm?page=445

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I.   INTRODUCTION

A.   OVERVIEW

According to retired Navy Captain Dr. Nick Davenport of the Naval Safety Center, "Fatigue is a major factor in many mishaps and can contribute to injury, equipment damage, and loss of life" (Davenport, 2013, p. 1). U.S. Navy sailors and officers are exposed to a myriad of dangers every day, both while deployed and in port. Their jobs are inherently dangerous, and this danger cannot be avoided. U.S. Navy personnel must perform challenging tasks under pressure and with little or no room for error. They are called upon to do these tasks day-in and day-out, 24 hours a day, 365 days a year, in some of the harshest environments imaginable. Mistakes occur as a result of these high- stakes and high-risk evolutions, but some of these mistakes could be avoided.

Due to the requirement of U.S. Navy warships to operate 24 hours a day while operationally deployed, the crew performs its duties while operating in a shiftwork environment. Even more challenging is when these shifts are continually rotating, which causes the crew to sleep at different times each day and adapt to a constantly changing schedule. Unfortunately, this rotational work routine greatly disrupts enlisted sailors' and officers' sleep cycles and circadian rhythms. Thus, while performing extremely dangerous and challenging missions of tremendous national and global importance, many U.S. Navy sailors and officers are doing so in an environment that leaves them clinically and critically sleep deprived. The consequences of sleep deprivation and fatigue can be disastrous, as demonstrated by the accidents at Chernobyl Reactor 4, Three Mile Island Unit 2, Bhopal Union Carbide, and the *Exxon Valdez* oil spill (Chiles, 2002). The U.S. Navy is certainly not immune to similar types of incidents.

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Yet, facilitating the changes in watch rotations and schedules that are necessary for maintaining a well-performing naval force cannot be instituted without addressing the method by which the U.S. Navy determines required manning levels for ships. In order to determine the personnel assigned to each class of ship, the Navy designed, and still utilizes, a standardized version of one week of activity performed while at sea. This standard week is referred to as the Navy standard workweek (NSWW). The NSWW designates 81 hours per week for available time or on-duty time and 87 hours per week for non-available time

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B. BACKGROUND

This study is the initial investigation of a two-phase study of the sleep, fatigue, performance, and work schedules of sailors onboard the aircraft carrier USS *Nimitz* (CVN-68). Crewmembers, Carrier Air Wing 11, and Carrier Strike Group 11 of the USS *Nimitz* departed their homeport nearly three months later than scheduled, on 29 March 2013, due to required emergent maintenance on elements of its propulsion plant system. During its nearly eight-month-long Western Pacific (WESTPAC) deployment, the *Nimitz* participated in a Sustainment Exercise (SUSTEX), joint exercises with the Republic of Korea Navy, supported Operation Enduring Freedom (OEF) by launching over 1,400 combat sorties in the Fifth Fleet area of responsibility (AOR), supported U.S. national interests in the Middle East from the Red Sea, transited the Suez Canal, and participated in joint exercises in the Mediterranean Sea in the Sixth Fleet

AOR. During the period in which this study was conducted (August 26, 2013 to September 24, 2013), the ship conducted flight operations while transiting the Arabian Sea and transited through the Bab-el-Mandeb Strait into the Red Sea in order to support U.S. national interests in the Middle East.

C.   OBJECTIVES

Limited research has been conducted on the sleep, fatigue, performance, and work schedules of sailors' onboard aircraft carriers. Furthermore, what little research that has been conducted is focused on only short periods of abnormal operations and on departments other than the reactor department. This thesis aims to investigate the sleep, fatigue, performance, and work schedules of sailors and officers during normal steaming and flight operations, with an emphasis on comparing different groups and departments of the ship, including the reactor department. This thesis has the following purposes:

- Determine the amount and quality of sleep each participant received and assess whether differences exist between various groups, departments, and watch rotations. Determine if sleep is related to demographic and sleep analysis survey data collected during the study.

- Compare participants' self-reported sleep to actigraphic sleep. Examine whether sleep deprivation affects participants' ability to accurately determine how much sleep they received.

- Determine the amount of time that sailors spent sleeping, working, and participating in other activities, as compared to the NSWW, in order to assist in determining if the NSWW is an accurate tool for determining manning levels on U.S. aircraft carriers.

- Using FAST, determine the predicted effectiveness of sailors during watch periods and other critical times.

D.   SCOPE, LIMITATIONS, AND ASSUMPTIONS

Data collection for this thesis was limited to 35 enlisted sailors and officers aboard the USS *Nimitz*. A U.S. aircraft carrier was chosen due to the limited amount of sleep and fatigue data available for aircraft carriers, in general, and for reactor departments specifically. Although data was collected during three

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overlapping periods, operations were similar enough among the different periods to allow the data to be considered as a single data set. Since each watchstander is critical to the success or failure of the ship's mission, an effort was made to seek participants from a cross-section of watchstanders from various departments and groups. Specifically, the Reactor Department was targeted for recruitment due to the limited amount of sleep, fatigue, and performance data available for nuclear-qualified personnel on U.S. aircraft carriers. The three main departments (groups) recruited were the Deck Department, the Reactor Department, and officers. This sample of participants allowed for a comparison between diverse groups on different work and watch schedules. Among the 35 volunteers offering to take part in the study, only 32 participants had complete actigraphy data and only 26 had both complete actigraphy and activity and sleep log data. The data were collected in a minimally invasive manner to avoid interfering with the daily requirements and duties already placed upon the crew.

Although the use of polysomnography (PSG), a technique used to monitor a person's sleep through the recording of brain waves and other physiological factors, is the ideal method for collecting sleep data, due to the operational setting of the aircraft carrier, wrist-worn activity monitors (actigraphs) were used to collect sleep and activity information for each of the participants. Actigraphy is a well-established and accepted means for determining sleep-wake discrimination. The concordance rate between actigraphy and PSG has been determined to be as high as 95% for detecting sleep (Paquet, Kawinska, & Carrier, 2007). Actigraphy monitors, however, are limited in their ability to detect waking epochs during sleep. Concordance rates for detecting short awakenings while asleep have been assessed to be as low as 34% to 44%. Actigraphy, however, is still a very useful tool for assessing sleep and activity of humans, especially in field environments (Souza et al., 2007).

The Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model (see Chapter II, Section I.4), was implemented using a Microsoft Windows program called SAFTE-FAST. SAFTE-FAST was used to predict and quantify the

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cognitive effectiveness of each participant over the period in which they participated in the study. Predicted effectiveness of participants while on watch was specifically investigated. The strengths and weaknesses of the SAFTE model are described in greater detailed in Chapter II, Section I.4.c.

The study was observational in nature in that it lacked baseline data from well-rested conditions for each participant and there was no control group. The participants were recruited voluntarily and did not represent a random sample of the entire ship's population. Additionally, since the data were collected on a single aircraft carrier over a specific period of time, caution is warranted when seeking to generalize the results presented in this thesis to other U.S. Navy vessels and operational units.

E.   THESIS ORGANIZATION

Chapter II reviews the literature on major concepts related to sleep deprivation and shiftwork. Chapter III presents the methodology used in the thesis. Chapter IV describes the analytical strategy, presents the statistical results, and provides a discussion of the results. Finally, Chapter V presents conclusions and recommendations for U.S. Navy leadership and future research.

II.   LITERATURE REVIEW

A.   OVERVIEW

Today humans live in a 24/7, around-the-clock society. Even though working hours, for most people, are decreasing worldwide compared to 100 years ago, people are increasingly seeking lifestyles that leave little time for rest or sleep. The world's modern and highly competitive, 24/7 economy increases the demand for nonstandard, irregular working hours. Forty percent of all employed Americans work on schedules other than the traditional 9-to-5 work day. Furthermore, 15%–20% of workers in all industrialized nations assume a nontraditional work schedule (Haus & Smolensky, 2006), which are highly disruptive to sleep and increase the risk of sleep disorders, require individuals to work evenings, nights, and/or rotating shifts (Presser, 2003). Some researchers suggest that other broad societal changes, such as greater access to television and the internet, are contributing factors to increased sleep loss (Monk, 2005).

Working hours have been on the rise in the United States. U.S. workers spend 200–400 hours more per year at work than their counterparts in Germany, France, Norway, Sweden, and Denmark (Organization for Economic Cooperation and Development [OECD], 2002). This trend of increased working hours is readily apparent among some of the most critical professions in our society. The National Aeronautics and Space Administration (NASA), for example, places intense work-hour demands on its employees, with its "faster-better-cheaper" tactic, often leading to 80-hour work weeks (Chiles, 2002, p. 164). Healthcare professionals, such as nurses and physicians, face pressure to work long hours with little regulation or enforcement of working-hour limits. Regulations that are in place remain inadequate. For example, the Boston Police Department places a work-hour limit of 96 hours per week on its employees, which still allows for almost 14-hour workdays (Johnson & Lipscomb, 2006).

Sixty-three percent of Americans report that their sleep needs are not being met (National Sleep Foundation [NSF], 2011). Certainly, long and irregular working hours are a significant factor affecting the American worker. Human cognitive function and neurobehavorial performance are deleteriously impacted as a result of sleep loss and function (Lamond & Dawson, 1999). A multitude of studies link sustained wakefulness to reductions in human performance in regards to decision making, memory, hand-eye coordination, and speed and accuracy (Akerstedt, 1988; Belenky et al, 2003; Caruso, 2014; Dawson & Reid, 2013; Dinges & Kribbs, 1991; Van Dongen, Maislin, Mullington, & Dinges, 2003) As a result, humans make errors when they are sleep deprived. Real-world tragedies such as Chernobyl Reactor 4, Bhopal, and Three Mile Island Unit 2 can all be linked, at least in part, to sleep deprivation (Chiles, 2002).

If the average American is lacking adequate sleep, certainly one can imagine the difficulties that a member of the U.S. Navy faces in regards to getting proper rest. The U.S. Navy's interest in understanding sleep as it pertains to human performance has greatly expanded over the last 15 years as a result of the increased operational tempo of modern warfare. Today, senior leaders are concerned about both the short- and long-term consequences of sleep deprivation; however, watchbills, shift-rotations, and schedules that facilitate adequate sleep, while at the same time supporting 24-hour operations, are still lacking. Thus, achieving adequate sleep continues to be a problem for U.S. Navy enlisted sailors and officers.

This chapter reviews the literature on the fundamentals of sleep, sleep deprivation, and human performance. It reviews the literature on sleep architecture and circadian rhythms in humans. The effect of shiftwork and shift rotations and circadian rhythms is addressed. The chapter also covers the effects of sleep deprivation on health and human performance. The fatigue model used as the basis for this research is described. Past studies of U.S. Navy aircraft carriers are reviewed. Finally, IMPRINT Pro is also described.

B.   SLEEP

Humans, like other higher organisms, have a biological requirement for sleep in order to sustain life and health—similar to our need to eat and drink. The National Sleep Foundation (NSF) recommends that a typical healthy adult receive 7 to 9 hours of sleep per day (NSF, 2014c). Table 1 shows the average sleep needs for a typical human lifecycle; however, sleep needs vary by individual, ranging from 6 to 10 hours (Neri, Dinges, & Rosekind, 1997). Young adults and teenagers (the majority of U.S. Navy personnel) need more sleep in order to fully recover from physical stressors (Giam, 1997).

Age	Sleep Needs (Hours per Day)
Newborns (0-2 months)	12 to 18
Infants (3 to 11 months)	14 to 15
Toddlers (1-3 years)	12 to 14
Preschoolers (3-5 years)	11 to 13
School-age children (5-10 yea	10 to 11
Teens (10-17 years)	8.5 to 9.25
Adults	7 to 9

Table 1.   Average sleep needs over a typical human life cycle (after NSF, 2014c).

Human sleep patterns are controlled by the circadian rhythm that cycles roughly once every 24 hours (Colten & Altevogt, 2006). This "biological clock" encourages humans to be awake and alert during the day and asleep during the night. Several physiological and psychological functions, such as body temperature, growth hormones, blood pressure, and alertness, noticeably fluctuate throughout a 24-hour cycle (Colten & Altevogt, 2006). As a consequence, human performance is degraded at night and in the early morning hours.

1.   Sleep Architecture

Within the sleep science community, the structural organization of sleep is referred to as "sleep architecture." During a complete eight-hour sleep episode, a typical healthy adult experiences two types of sleep: non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep. NREM sleep is divided into stages 1 through 4, with each stage being a "deeper" form of sleep than the previous one (Colten & Altevogt, 2006). REM sleep follows stage 4 of NREM sleep; however, individuals will cycle back through the NREM and REM stages of sleep several times throughout a night of sleep, as shown in Figure 1 (Colten & Altevogt, 2006). The first NREM to REM sleep cycle requires approximately 70 to 100 minutes to complete, while the later cycles take somewhat longer, lasting approximately 90 to 120 minutes (Colten & Altevogt, 2006).
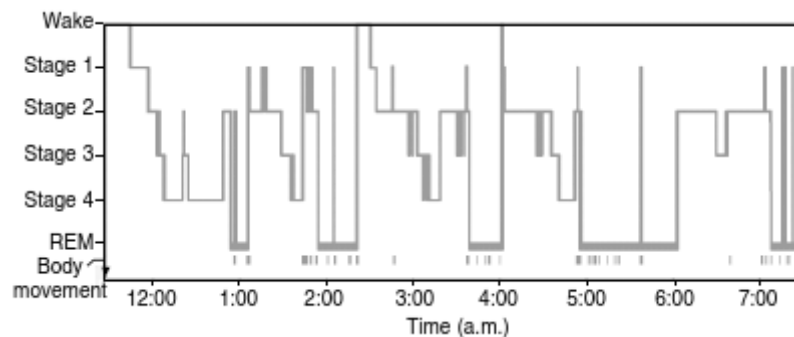
Figure 1.   A typical sleep cycle (from Colten & Altevogt, 2006, p. 34).

In normal adults, NREM sleep accounts for roughly 75%–80% of the time spent asleep, while REM sleep accounts for the remaining 20%–25% (Colten & Altevogt, 2006). Each stage of sleep is characterized by changes in brain-wave patterns, eye movements, muscle tone, and other physiological and psychological changes as described in Table 2 (NSF, 2014a).

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Sleep Stage	Description
NREM: 75% of the night	As we begin to fall asleep, we enter NREM, which is composed of stages 1-4.
Stage 1	Light sleep; between being awake and entering sleep.
Stage 2	Onset of sleep; becoming disengaged with the environment; breathing and heart rate are regular and body temperature decreases.
Stage 3 & 4	Deepest and most restorative sleep; blood pressure drops; breathing slower; energy regained, and hormones are released for growth and development.
REM: 25% of the night	First occurs about 90 minutes after falling asleep and increases over later part of night; necessary for providing energy to brain and body; brain is active and dreams occur as eyes dart back and forth; body becomes immobile and relaxed, muscles shut down; breathing and heart rate may become irregular; important for daytime performance and may contribute to memory consolidation.

Table 2.   Description of sleep stages (after NSF, 2014a).

a.   *Non-Rapid Eye Movement Sleep*

Non-REM sleep is composed of four stages, each characterized by unique brain activity or brain waves, as recorded by an electroencephalographic (EEG) (see Figure 2) (Colten & Altevogt, 2006). Stage 1 serves as a transitional phase from wakefulness and usually lasts 1–7 minutes in the first sleep cycle of the night (Colten & Altevogt, 2006). A person is easily awoken in stage 1 and only spends 2%–5% of their total sleep in this stage. Brain activity is characterized by rhythmic alpha waves and low-voltage, mixed-frequency waves (Colten & Altevogt, 2006).
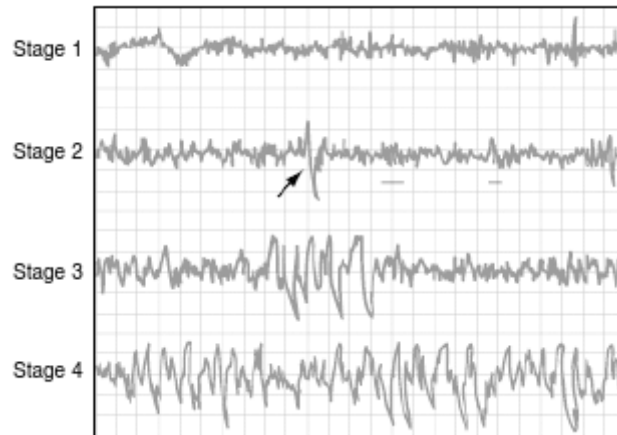
Figure 2.   Characteristic EEG activity for the four stages of NREM sleep. The underlining shows two sleep spindles (from Colten & Altevogt, 2006, p. 36).

In the first sleep cycle of the normal sleep episode, stage 2 sleep is roughly 10–25 minutes long (Colten & Altevogt, 2006). During later sleep cycles, stage 2 sleep lengthens, eventually accounting for the majority of NREM sleep. Low-voltage, mixed-frequency waves make up the majority of brain activity. Sleep spindles, thought to be important for the consolidation of memories, appear during this stage as well (Colten & Altevogt, 2006).

Stages 3 and 4 are associated with the deepest and most restorative levels of sleep and are jointly referred to as slow-wave sleep (Xie et al., 2013). Stage 3 lasts only several minutes, making up for roughly 3%–8% of total sleep (Colten & Altevogt, 2006). Stage 4, lasting about 20–40 minutes, accounting for 10%-15% of sleep (Colten & Altevogt, 2006). An individual requires the most intense arousal stimuli in this stage of sleep. Both stages 3 and 4 are characterized by high-voltage, slow brain-wave activity (Colten & Altevogt, 2006).

b.   *Rapid Eye Movement Sleep*

REM sleep is recognized through the presence of desynchronized, low-voltage, mixed-frequency brain-wave activity (Colten & Altevogt, 2006). This stage gets its name from the bursts of "rapid eye movements" that accompany it (Colten & Altevogt, 2006). During this stage of sleep, brain-wave activity is similar

to an awakened state, with "sawtooth" wave forms and slow alpha activity, leading some researchers to refer to REM sleep as "paradoxical" sleep (Siegel, 2000). Most dreaming occurs during this stage as well. Thus, muscle atonia serves to prevent individuals from acting out their dreams throughout the night (Colten & Altevogt, 2006).

During his or her first sleep cycle of a sleep episode, an individual obtains only 1–5 minutes of REM sleep; however, REM sleep becomes gradually longer as the sleep episode continues (Carskadon & Dement, 2005). REM sleep also may contribute to memory consolidation (Crick & Mitchison, 1983; Smith & Lapp, 1991; Stickgold & Walker, 2007).

2.   Sleep Debt

As a result of shiftwork, transmeridian travel, the use of stimulants, and personal sleep choices, people regularly do not get enough sleep. Sleep debt is the difference between the minimum amount of sleep that a person requires and the amount of sleep that he or she actually obtains (Chapman, 2001). As an individual's sleep debt increases, their mental alertness and performance continues to degrade. Only 1–2 hours of sleep loss can significantly reduce human performance. Consequently, it is not surprising that every year sleep debt leads to injuries, diminished lives, and death (Dement & Vaughn, 2000).

Sleep debt is incurred and becomes "chronic" when inadequate sleep is obtained on a regular basis (Van Dongen, Rogers, & Dinges, 2003). Chronic sleep debt can lead to serious physical and mental health issues (Schaefer, Williams, & Zee, 2012). A 2002 NSF poll found that the average adult American is only sleeping 6.9 hours per day during the week. Thus, a large portion of the U.S. population is regularly starting the weekend with at least 5.5 hours of sleep debt. The NSF considers sleep debt a rising health concern in the United States (NSF, 2002).

Sleep pressure, or one's homeostatic sleep drive for sleep as a function of the amount of time elapsed since the last adequate sleep episode, builds as

cumulative sleep debt increases (Van Dongen, Rogers et al., 2003). Eventually, a person's sleep pressure becomes so great that uncontrolled sleep episodes or microsleeps occur (Van Dongen, Rogers et al., 2003). Such episodes can occur even while a person is standing up or actively in the middle of a task (McCallum, Sanquist, Mitler, & Krueger, 2003). Microsleeps are a serious concern of any industry that restricts personnel sleep time such as hospitals, emergency response personnel, and especially the military.

3. Recuperative Sleep

The only way to recover from a cumulative sleep loss is to extend sleep in subsequent nights. Interestingly, a cumulative sleep debt usually cannot be replenished in a single night of sleep, as found by Dinges et al. in a 1997 study concerning partial sleep deprivation. Many people go into a weekend with the assumption that they will "sleep in" in order to replenish the substantial sleep debt that they accumulated throughout the workweek (NSF, 2002). Such an assumption, however, is faulty in that a large sleep debt may take more than only a few nights of extra sleep to fully replenish. As a result, an individual's sleep debt continues to accumulate, eventually becoming "chronic" and possibly leading to serious physical and psychological consequences.

Several studies show that sleep debt is not replenished on an hour-for-hour basis. Belenky et al. (2003), at the Walter Reed Army Institute of Research (WRAIR), showed that three days of recuperative sleep was still not enough to recover the performance decrements suffered as a result of sleep deprivation. Figure 3 graphically illustrates the substantial recovery time required.
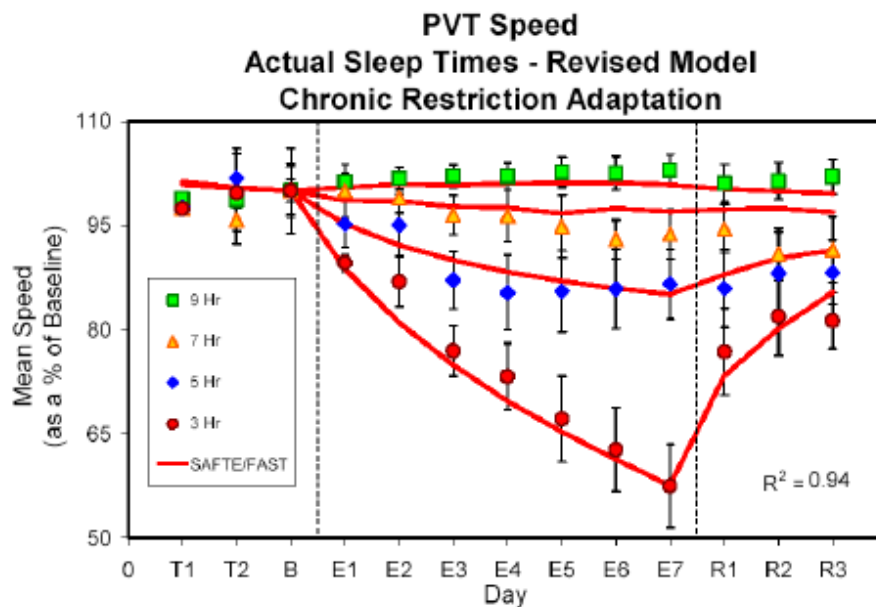
Figure 3.   Sleep response (after Belenky et al., 2003, p. 6).

4.   Morningness-Eveningness Sleep Preference

Dement and Vaughn (2000) discuss morning-evening sleep preference. Individuals not only differ in the amount of sleep they need, but also differ in their bedtimes and wake-up times. People who prefer to wake up early in the morning are called "larks," or are said to have a propensity toward "morningness." As a result, larks tend to get tired earlier in the evening and have earlier bedtimes. On the other hand, "owls," those individuals having a propensity toward "eveningness," prefer to wake up later in the morning and go to bed later at night. An individual who experiences neither of these extremes is referred to as a "robin" or a "hummingbird." "Larks" tend to experience peak alertness in the morning, while "owls" are more alert in the evening. Interestingly, the onset of adolescence is accompanied by a general eveningness preference that may persist until the mid-twenties. Once this period is past, however, individuals tend to revert to their normal morningness-eveningness preference and become more lark-like (Dement & Vaughn, 2000).

C. SLEEP-WAKE REGULATION

Several factors influence when individuals go to sleep at night and when they wake up in the morning. The "two-process model" states that the sleep-wake system is regulated by these two competing processes; one promoting sleep (process S) and one maintaining wakefulness (process C) (Gillette & Abbot, 2005). On top of these two processes, an individual's circadian rhythms regulate and assist in synchronizing the sleep-wake system with the external day-night cycle (Colten & Altevogt, 2006). A "three-process model" is also used to explain sleep-wake regulation; however, it will be explained in a later section concerning the various models of human performance and fatigue. The Two-Process Model is used to explain sleep-wake regulation in this section.

1. Sleep and Wake Generating Systems

Process S, the homeostatic pressure for sleep, builds up throughout the day and reaches a peak before a person's bedtime. It subsequently dissipates throughout a good night's sleep (Colten & Altevogt, 2006). This process is controlled by neurons that inhibit arousal systems in the brain, thus allowing the brain to fall asleep. In fact, loss of these particular neurons causes intense insomnia (Colten & Altevogt, 2006). Other areas of the brain assist in controlling one's sleep system. For example, the physical status of one's body, such as a full stomach and emotional cognitive state act as inputs as well (Colten & Altevogt, 2006).

Process C, controlled by the circadian system, helps to maintain the sleep-wake system in sync with environmental day-night cycles. This process counters process S throughout the day in order to promote alertness during daylight hours (Colten & Altevogt, 2006); at bedtime, process C declines, allowing for sleep consolidation (the accrual of sleep into a singular episode) (Gillette & Abbott, 2005). After a good night's sleep, process S is dissipated and process C increases, which restarts the cycle (Colten & Altevogt, 2006).

2. Circadian Rhythms

Circadian rhythms are daily fluctuations in the physiological and psychological functions, as governed by the by the body's approximately 24-hour biological clock. "Circadian," from the Latin roots *circa* meaning "about" and *dies* meaning "day," literally means "about a day" (McCallum et al., 2003). Many daily processes and bodily functions, such as mood, alertness, reaction time, muscle tone, digestion, respiration, hormone secretion, and body temperature, are controlled by an individual's biological clock.

The body's biological clock is located in the suprachiasmatic nucleus (SCN), or master-oscillator, of the hypothalamus. SCN cells produce a roughly 24-hour rhythm, which affects the peripheral oscillators of the central nervous system and many bodily functions (Schaefer et al., 2012). The two-process model of sleep-wake regulation is formed by the interaction of the SCN and circadian rhythms. As sleep pressure builds during the day, SCN neuron activity increases, maintaining daytime wakefulness. Eventually, usually in the early evening, activity in the SCN peaks and then begins to wane, in order to promote sleepiness (Schaefer et al., 2012).

a. Exogenous Time Cues

The endogenous biological clock typically runs slightly longer than 24 hours, requiring daily resynchronization to the 24-hour day. This process, known as entrainment, involves the human clock receiving environmental cues, or *zeitgebers* (German for "time givers") (Winget, DeRoshia, & Holley, 1985). Daily changes in light and dark play a central role in synchronization; however, other social cues, such as meal times, also act in lining up one's biological clock with the 24-hour day (Winget et al., 1985). Without these exogenous factors, circadian rhythms extend to a 25-hour cycle, explaining why many people find it easier to stay up later (a phase delay or lengthening of the day) as opposed to going to bed earlier (a phase advance or shortening of the day) (Neri et al., 1997).

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b. Body Temperature

Daily fluctuation in core body temperature, as shown in Figure 4, has a profound influence on human sleep and plays a key role in human circadian rhythms. Contrary to popular belief, body temperature varies approximately 0.5 degrees throughout the day regardless of arousal state (Roehrs, Carskadon, Dement, & Roth, 2000). Interestingly, studies have shown that without exogenous time cues, body temperature remains a strong governing force regulating sleep (Roehrs et al., 2000). Furthermore, a person's sleep cycle and body temperature will often "free run," or come to a 24-hour period, rather than to a 25-hour endogenously determined period (Hockey, 1983).
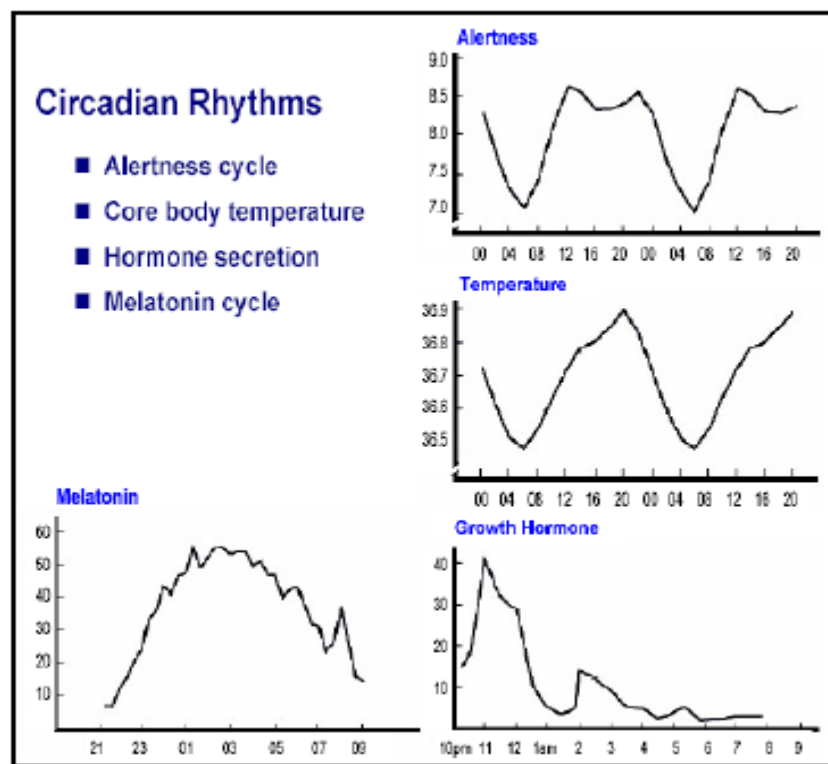
Figure 4.   Circadian rhythm of alertness, core body temperature, hormone secretion, and melatonin (from McCallum et al., 2003, p. 5-3).

c. Melatonin

Secreted by the pineal gland, melatonin assumes an important role in managing an individual's circadian rhythm. Light information, passed from the retina of the eye to the SCN, regulates melatonin production. Elevated levels of melatonin result in increased sleepiness in humans. Well-timed doses of exogenous melatonin assist in causing sleepiness and can be useful in resetting an individual's circadian clock (Baker & Zee, 2000). Melatonin levels fluctuate throughout the day, usually reaching a minimum during midmorning and a peak between 0300 and 0500 (Czeisler & Khalsa, 2000). These levels make sense, as humans are biologically programmed to sleep at night and be awake and alert during the day.

d. Circadian Misalignment

When individuals attempt to sleep or be awake at times not in agreement with their biological clock, a phenomenon known as circadian misalignment occurs (Schaefer et al., 2012). Otherwise referred to as an abrupt phase delay or advance, such as those encountered when traveling across time zones or working shiftwork schedules, this misalignment can have profoundly negative short- and long-term effects (Schaefer et al., 2012). Problems such as poor sleep, shiftwork disorder (SWD), mistakes at work, and long-term health consequences often occur in circadian misalignment (Schaefer et al., 2012).

D. SHIFTWORK

A traditional 9-to-5, eight-hour workday is becoming rare in today's society. Nearly 20% of all employed Americans and 15%–20% of workers in all industrialized nations work mostly during the evening, night, or on rotating shifts (Haus & Smolensky, 2006). Daytime shifts often start as early as 0600 and end as late as 1800. Evening shifts often start at 1400 and continue until 2400. Night shift schedules may start as early as 2200 and not end until 0800. Sleep deprivation is a characteristic observed in all night and rotating shift workers. While working during the night or early morning hours, almost 75% of shift

workers experience fatigue and sleepiness while at work (Akerstedt, 1988). As a result, shiftwork schedules can often adversely impact an individual's overall health, lead to marriage dissatisfaction, and increase accidents in the workplace (Johnson & Lipscomb, 2006).

1.   Reasons for Shiftwork

Shiftwork schedules exist in a multitude of different professions for various reasons. The emergency medical community operates on a 24/7 schedule in order to provide on-site patient care throughout the night. Firefighters and police officers work rotating shift schedules so that personnel are always prepared to respond to emergencies and crimes. Naval organizations, with ships at sea, adopt the most demanding of all shift schedules in order to support 24-hour-a-day combat operations throughout the world.

Presser (2003) argues that the demand for workers willing to adopt irregular hours of shiftwork type schedules is increasing. Due to macro-level social factors, such as the rise of the service economy, more workers are taking jobs that require nonstandard working hours (Presser, 2003). Even though some workers prefer a nontraditional schedule, most do not actively pursue shiftwork (Rosa & Colligan, 1997). Workers sometimes choose shiftwork for better pay, more time for social activities, and because irregular hours, such as the night shift, offer quieter working conditions with fewer supervisors. Others simply choose shiftwork because it is required and no other employment opportunities are available (Rosa & Colligan, 1997).

2.   Circadian Phase Shifting

Haus and Smolensky (2006) discuss circadian phase shifting. A circadian phase shift occurs when a person must adopt a new activity-sleep schedule and is no longer governed by the normal, light-dark cycle and social routines. Such a schedule, for example, could involve night work, rotating shiftwork, or transmeridian travel. A phase shift causes a transient loss of control by the SCN due to a desynchronization of the central and peripheral oscillators in the central

nervous system. This process is often referred to as circadian misalignment. Eventually, after several transient cycles, the SCN and peripheral oscillators will adapt to the new irregular schedule, although almost never fully adapting (Haus & Smolensky, 2006).

Phase shifting results in serious short-term consequences. Peak periods of physical efficiency are often moved from the late afternoon to night and the proclivity to sleep may be low during periods available for rest, while desire to sleep is high during times when alertness and mental acuity are required (Haus & Smolensky, 2006). Furthermore, while the body is still in a period of temporal adaptation, individuals often feel sluggish or groggy, symptoms similar to those of jet lag. Workers suffering from such symptoms are more likely to be involved in work place accidents (Haus & Smolensky, 2006). Ample evidence exists to prove that circadian misalignment is a source of mistakes and severe, on-the-job accidents (Schaefer et al., 2012).

3.   Shiftwork Timing

The timing of a worker's shift is important because often it forces him or her to follow a schedule that is out of phase with normal environmental and social cues (Haus & Smolensky, 2006). Thus, a person working late at night or early in the morning must constantly fight their circadian clock in order to stay awake and alert while on the job. Often, workers feel sleepy and lethargic while working the night shift (Rosa & Colligan, 1997). Thus, it is not surprising that, compared to the day shift, workers on the evening shift are 15% more at risk for errors and incidents, while night shift workers are 28% more at risk (Folkard & Lombardi, 2006).

Shift workers are often required to try to sleep at times of the day that are not in tune with their biological clock. Specifically, night workers are required to sleep during the day, usually in the late afternoon to evening hours (Haus & Smolensky, 2006). This timing is in direct conflict with one's circadian rhythm due to several factors. First, SCN activity is near its peak, which promotes

wakefulness. Second, melatonin levels in the body are extremely low, also promoting alertness. Third, body temperature is also higher than optimally required for sleep. All of these factors conspire, making it difficult to obtain an adequate amount of quality rest during daylight hours (Haus & Smolensky, 2006).

Day workers must often wake up in the early morning hours, sometimes as early as 0500 (Rosa & Colligan, 1997). As a result, these workers are often forced to cut off their sleep, which leads to daytime fatigue and sleepiness. Furthermore, day workers often must go to bed earlier than allowed for by their circadian rhythm, further aggravating their sleep schedule (Rosa & Colligan, 1997).

4.   Shiftwork Schedules

Rotating and permanent shiftwork schedules and the direction of shift rotations are described in this section.

a.   *Permanent*

Permanent shift schedules are those in which an individual works only one shift: day, evening, or nights (Rosa & Colligan, 1997). Shiftwork-related sleep loss and fatigue occur even in permanent night workers. Even after an extended period of time (months or years) on this shift, very few night workers display any phase adjustment of their circadian clock (Schaefer et al., 2012). Unfortunately, most experience no change or a circadian disruption, leading to sleep debt (Schaefer et al., 2012).

Further contributing to difficulties in phase adjustment are social influences. Permanent night workers often go back to a normal day-night schedule on their days off in order to spend time with family or run errands (Rosa & Colligan, 1997). Additionally, night workers not only get less sleep when they sleep during the day, but that sleep is of a lower quality as well (Rosa & Colligan,

1997). Attempting to sleep during the day is in direct conflict with one's circadian rhythm; therefore, falling asleep and staying asleep is more difficult (Rosa & Colligan, 1997).

b.   Rotating

A rotating shift schedule is one in which an individual switches their shift after some given time period. By following this method, an individual rotates to a new shift schedule every 3–4 days (rapid rotation) or weekly (intermediate to slow rotations) (Haus & Smolensky, 2006). Many 24/7 organizations, such as the U.S. Naval Nuclear Power Training Units in Ballston Spa, New York and Charleston, South Carolina, adopt rotating shift schedules because they are considered more fair since every person on the workforce takes his or her turn working each shift.

Regrettably, this type of schedule allows for little or no phase adaptation. Even though most shift workers on rapid rotations can maintain a normal day-night circadian rhythm, quick rotations are not necessarily optimal for worker performance. For example, a night worker, experiencing little or no phase adjustment, will not only be fatigued, but his or her physical and cognitive abilities will be severely diminished (Haus & Smolensky, 2006). Intermediate or slow rotations often lead to a phase alteration but never allow for a phase adaptation. This form of rotation can lead to significant disruptions of one's circadian clock, possibly leading to shiftwork intolerance or SWD, a circadian rhythm sleep disorder (CRSD) (Haus & Smolensky, 2006).

c.   Rotation Direction

The direction of shift rotation is an important consideration for phase adaptation of shift workers. Direction of rotation refers to the sequence of shift variation (Rosa & Colligan, 1997). For example, a forward rotation starts on the day shift and continues to the evening and night shifts. This rotation can also be thought of as rotating in the clockwise direction. In contrast, a backward shift rotation still starts on the day shift, but then progresses to the night and the

evening shift. This schedule can be thought of as rotating in the counterclockwise direction. Regardless of rotation direction, some amount of circadian desynchrony occurs in all shift workers on a rotating schedule because they are continuously forced to not only alter their sleep schedule, but must often sleep at nonoptimal times of the day-night cycle (Rosa & Colligan, 1997). Consequently, sleep is a challenge for rotating shift workers.

Initially, sleep experts presumed that rapidly advancing 8-hour rotating schedules were unfavorable. This theory was mainly due to the slower adaptation to a phase advance versus a phase delay as observed in clinical trials (Haus & Smolensky, 2006). Recently, however, several studies have found that forward-rotating schemes produced positive effects on sleep and shift worker health (Hakola & Härmä, 2001; Härmä et al., 2005). Some researchers suggest that a forward rotation is better because it forces a worker to go to bed later and wake up later following a shift rotation. The human circadian rhythm already makes one feel alert and energetic in the early evening, which makes it much harder to fall asleep earlier than later. In contrast to forward rotations, backward rotating shifts compel a worker to go to bed earlier and earlier after each shift change, shortening the length of a day, in direct conflict with one's circadian clock (Rosa & Colligan, 1997).

5. Sleep Duration

Studies show that the amount of sleep a shift worker receives is influenced by the type of shift schedule they are working. A meta-analysis conducted by Pilcher, Lambert, and Huffcutt (2000) of 36 separate studies revealed that permanent day workers (shifts that start between 0700 and 0900) slept an average of 7.0 hours per day, permanent and rotating evening-shift workers (shifts that start between 1400 and 1700) slept 7.6–8.1 hours, permanent night-shift workers (shifts that start between 2200 and 2400) slept 6.6 hours, and rotating night-shift workers slept only 5.9 hours. Clearly, when working the night shift, rotating shift workers receive less sleep. Interestingly,

permanent evening-shift workers and those currently on the evening shift of a rotating schedule received the most sleep, even more so than permanent day workers. One possible explanation for this finding could be that the evening shift is more in line with the human circadian rhythm; therefore, it is easier to adjust to the evening shift, even if it is part of a rotating shift schedule.

A study conducted by Paley and Tepas (1994) examined firefighters working a rotating shift schedule at a northeastern public university. This fire station adopted a backward, or counterclockwise, shift rotation consisting of three different shifts: night (2400 to 0800), evening (1600 to 2400), and day (0800 to 1600). Specifically, a shift rotation consisted of two weeks on the night shift, then two weeks on the evening shift, and, finally, two weeks on the day shift. The study found that the firefighters' experienced the shortest amount of sleep while on the night shift, while there was no significant difference between the day and evening shifts. Additionally, firefighters' sleep length was, on average, longer at the beginning of the evening shift, suggesting that they were attempting to reduce the sleep debt accumulated during the night shift through recuperative sleep (Paley & Tepas, 1994).

6.   Long-Term Health Consequences of Shiftwork

A myriad of long-term negative health problems are linked to shiftwork. One of the main culprits for these negative consequences is chronic sleep loss. Other studies show that the problem is more complex than simple sleep debt. For example, one study concluded that "circadian stress," resulting from imbalances in psychosocial and physiological functions, results in circadian misalignment (Schaefer et al., 2012, p. 491). In 2007, the International Agency for Research of Cancer, a unit of the World Health Organization (WHO), identified circadian misalignment as a probable carcinogen (Schaefer et al., 2012). Poor health behaviors and other diseases and illnesses, such as gastrointestinal problems, are specifically associated with shiftwork. SWD is becoming a more widely recognized problem among rotating and night shift workers.

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a.   *Health Consequences of Sleep Loss*

The past two decades of sleep research have revealed the various long-term health consequences of sleep loss. Previously only thought to cause daytime sleepiness, sleep loss (a night's sleep shorter than seven hours), is now considered a culprit in several serious diseases and ailments (Colten & Altevogt, 2006). Obesity, diabetes, impaired glucose tolerance, cardiovascular disease and hypertension, high blood pressure, musculoskeletal disorders, myocardial infarction, cerebral vascular accidents, immune system depression, anxiety disorders, depressed mood, and alcohol abuse have all been associated with sleep loss (Colten & Altevogt, 2006). Furthermore, the severity of each disease increases with increasing sleep loss (Colten & Altevogt, 2006).

b.   *Health Consequences of Circadian Misalignment*

Many shift workers suffer from gastrointestinal ailments and moodiness (Sack, 2010). Specifically, many complain of abdominal pain, gas, diarrhea, constipation, nausea, vomiting, change in appetite, indigestion, and heartburn (Caruso, 2014). One major cause of gastrointestinal issues is the circadian desynchronization of meal times and the digestion system. Other factors include sleep deprivation, which causes stress; immune system dysfunction; and food availability while at work (Caruso, 2014).

Obesity is another serious health consequence of circadian misalignment. Research links hormonal imbalances, sympathetic nervous system issues, and irregular ghrelin and leptin levels caused by sleep restriction, to increases in appetite (Colten & Altevogt, 2006). In fact, research points to a positive relationship between obesity and shiftwork (Caruso, 2014).

Circadian misalignment is linked to cancer. Several studies have concluded that a connection exists between shiftwork-induced circadian misalignment and cancer. The 2007 WHO study concluded that data from human studies support a possible link. In 2005, a meta-analysis of 13 studies concluded that night work increased cancer risk by 48% (Caruso, 2014). Two of three

studies discovered an increase in prostate cancer among shift workers. Additionally, breast and colorectal cancers are also more prevalent among shift workers than among the general public (Schaefer et al., 2012). Regular shifting of sleep and work; immune system depression; and regular exposure to light at night, causing low melatonin levels, are all possible mechanisms that increase shift workers' risk of cancer (Caruso, 2014).

Some chronic diseases are exacerbated by shiftwork. Specifically, a person diagnosed with one of the following diseases could experience worsening symptoms if he or she assumes a shiftwork schedule: heart disease, high blood pressure, stomach and intestinal disorders, sleep disorders, insulin-dependent diabetes, seizure disorders, asthma requiring medication, psychiatric disorders, and alcohol and drug abuse (Colten & Altevogt, 2006). Shiftwork is also linked to adverse female reproductive health. In 2003, Frazier and Grainger found that shiftwork resulted in increases in spontaneous abortion, preterm birth, and reduced fertility in women.

c.   Shiftwork Disorder

SWD is one of many CRSDs. In fact, 10%–25% of rotating and night shift workers are diagnosed with SWD (Drake, Roehrs, Richardson, Walsh, & Roth, 2004). Symptoms include severe and chronic sleepiness, impaired performance during work hours, and poor sleep during the day (Schaefer et al., 2012). Individuals with SWD usually suffer from stomach ulcers, higher rates of depression, and a larger number of fatigue-related accidents for compared to other shift workers. SWD is most prevalent among night shift workers, but workers who begin a shift between 0400 and 0700 are also susceptible. Social and genetic factors also influence one's vulnerability to SWD (Schaefer et al., 2012).

SWD can be difficult to diagnose. The diagnostic criteria, as set forth by the International Classification of Sleep Disorders-2 (ICSD-2), are:

- Symptoms of insomnia that are associated with a work schedule that overlaps the usual time for sleep.

- Symptoms are directly associated with a shiftwork schedule over the course of at least one month.

- Sleep log monitoring for at least seven days demonstrates circadian and sleep-time misalignment.

- Sleep disturbance cannot be explained by another sleep disorder or by medical, neurological, or mental disorder; medication use; or substance-use disorder. (American Academy of Sleep Medicine, 2005)

d.   Poor Health Behaviors

Long work hours and shiftwork are linked to poor personal health habits. Bushnell, Colombi, Caruso, and Tak (2010) reported that a 12-hour shift rotation, determined to be detrimental to a person's health, was linked to high rates of smoking, obesity, low physical activity, and increased alcohol use. Smoking rates are generally higher among shift workers because nicotine serves as a countermeasure for fatigue and stress induced by their harsh schedules (Caruso, 2014). Finally, the consequences of shiftwork and long work hours, such as poor-quality sleep and reduced sleep length, often lead to obesity through hormonal and metabolic imbalances (Caruso, 2014).

E.   PERFORMANCE DECREMENTS CAUSED BY FATIGUE AND SLEEP DEPRIVATION

Many studies have examined the deleterious effects of both partial and total sleep deprivation on human performance. Of particular concern for the U.S. Navy is partial sleep deprivation. Sailors regularly face operating multibillion dollar equipment, while suffering from reduced cognitive and physical performance as a result of being chronically and acutely sleep-deprived.

1.   Total Sleep Deprivation

Total sleep deprivation results from a period of sustained wakefulness. The mental effects of complete sleep loss are substantial. In 1965, 17 year-old Randy Gardner purposely stayed awake for 264 hours (or about 11 days) for a

high school science project. He experienced significant deficits in concentration, motivation, perception, and higher mental processes (Tewari, Soliz, Billota, Garg, & Singh, 2011). Navy Lieutenant Commander (LCDR) John J. Ross of the U.S. Navy Medical Neuropsychiatric Research Unit in San Diego monitored Randy's condition throughout the experiment. He provided detailed documentation of Gardner's mental and physical condition on a daily basis. Ross reported that Gardner experienced memory loss, slurred speech, episodes of fragmented thinking, irritability, hallucinations, and paranoia at different times throughout the 11-day period (Ross, 1965). Gardner only recovered to his normal, preexperiment cognitive ability after several nights of normal sleep (Tewari, Soliz, Billota, Garg, & Singh, 2011).

A study at the University of Chicago conducted by Rechtschaffen and Bergman (2002) found that after five days of sustained wakefulness, rats actually die. Before the point of death, the sleepless rats displayed debilitated appearance such as ungroomed fur and various skin lesions, severe motor skill impairment, and substantially reduced brain activity (Rechtshaffen & Bergman, 2002). The symptoms described by Gardner in Ross's study are serious, even though they are only qualitative in nature.

A useful method for quantifying the performance impairment associated with total sleep deprivation is relating fatigue to alcohol-induced impairment. Lamond and Dawson (1999) sought to quantify the effects of sleep deprivation using this approach. They hoped to improve policymakers' and the general public's understanding of the performance decrements caused by sleep loss. Their study concluded that moderate levels of fatigue result in reductions in performance equivalent to or greater than those observed at levels of intoxication unacceptable when driving and/or operating heavy equipment. This general conclusion confirmed Dawson and Reid's (1997) earlier findings regarding sleep loss and alcohol intoxication. Furthermore, the 1999 Lamond and Dawson study systematically compared the effects of fatigue and alcohol intoxication in a quantifiable and scientifically repeatable experiment.

Lamond and Dawson's 1999 study also found that specific components of performance vary in their degree of sensitivity to sleep deprivation. Complex tasks were found to be generally more susceptible to sleep loss than simpler performance tasks. In addition, vigilance performance decreased as sleep loss increased (Lamond & Dawson, 1999). The extremely monotonous nature of vigilance tasks provides one explanation of perhaps why it was more sensitive to fatigue. Of note, Dinges, Whitehouse, Orne, and Orne (1988) found that tasks lacking complexity (such as simple reaction time tests) are affected early and intensely by sleep deprivation. This further suggests that monotony can increase performance decrements as a result of continued wakefulness (Lamond & Dawson, 1999). Clearly, mood, performance, and alertness are all negatively affected by total sleep loss.

2. Partial Sleep Deprivation

A multitude of studies show that the effects of partial sleep restriction seem to be cumulative in that as sleep loss continues to increase, performance and mood progressively deteriorate. Dinges and colleagues (1997) conducted an experiment involving the sleep restriction of 16 healthy, young adults. For seven consecutive nights, the participants' sleep was restricted to only five hours. The study concluded that the consecutive nights of restricted sleep negatively affected neurobehavorial markers of alertness; in particular, measures of sleepiness, fatigue, mood disturbance, stress, and lapses in psychomotor vigilance task (PVT) (Dinges et al., 1997). PVT is a method used to measure a subject's reaction time to visual stimulus. Research has linked lapses in PVT response and false responses to increased sleep debt in humans. Of note, scores on every performance and mood measure that were shown to be sensitive to sleep restriction progressively deteriorated during the final day, but only after initially *increasing* after the second day of sleep restriction. On the other hand, subjective sleepiness and fatigue immediately and substantially increased (Dinges et al., 1997).

Interestingly, Dinges et al. (1997) found that the effects of cumulative sleep loss seemed to level off between the second and fifth days of the experiment for subjective sleepiness and between the second and sixth days for the PVT performance, as shown in Figure 5 and Figure 6. Perhaps such a leveling off suggests some amount of "adaptation to sleep restriction" (Dinges et al., 1997, p. 274). Recovery from the seven days of partial sleep deprivation took at least two nights of recovery sleep (Dinges et al., 1997).
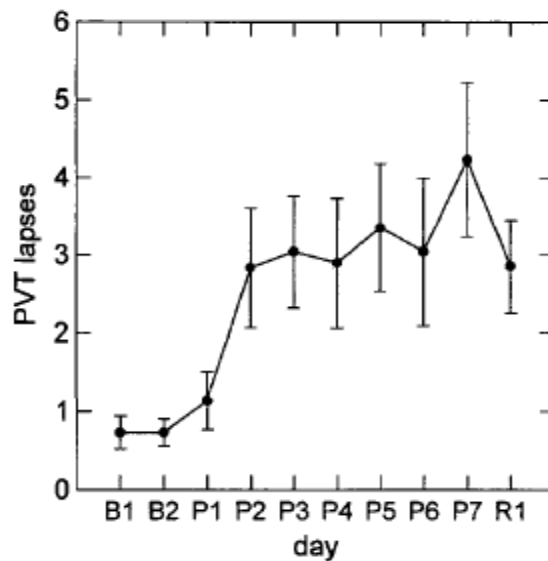
Figure 5.   Temporal profile of mean PVT lapses after two baseline nights (from Dinges et al., 1997, p. 273).
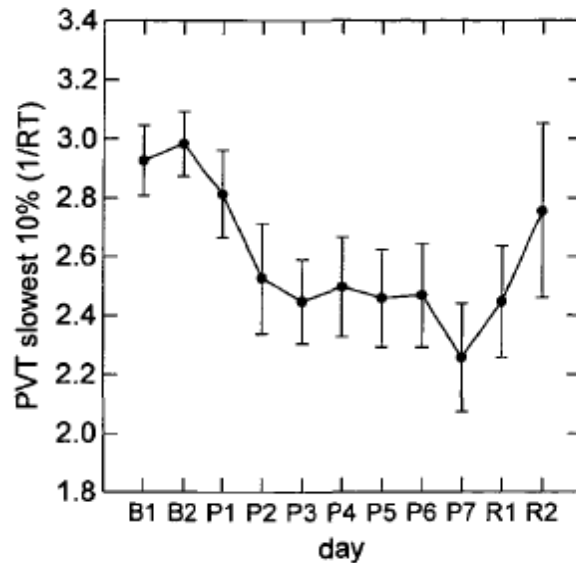
Figure 6.   Temporal profile of mean PVT duration of slowest 10% response
time (RT) responses in the lapse domain (from Dinges et al., 1997, p.
273).

Dinges' findings are consistent with the finding of a study conducted by Belenky et al. (2003) at WRAIR. The study at WRAIR found that PVT response speed $\left(\frac{1}{RT}\right)$ seemed to level-off in the middle three days of a seven-day study for sleep restricted to five hours per night, as shown in Figure 6. Results showed, however, that PVT speed dramatically worsened as a result of sleeping only three hours per night. In fact, by the seventh night, PVT response speed dropped to nearly only 50% of baseline PVT speed (Belenky et al., 2003).

A similar study conducted by Hans Van Dongen et al. (2003) found that chronic restriction of sleep periods to four or six hours per night over 14 consecutive days resulted in significant cumulative, dose-dependent deficits in cognitive performance on all tasks. Interestingly, only the subjects in the group receiving four hours of sleep reported that they felt sleepy. This result highlights the concern that sleep deprived people often are not aware of their own deteriorating performance. (Van Dongen et al., 2003). Clearly, cognitive performance is reduced as a result of partial sleep deprivation.

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F. FATIGUE COUNTERMEASURES: PREVENTION OF SLEEP-INDUCED PERFORMANCE IMPAIRMENT

Many techniques and substances exist to counteract fatigue and promote alertness and human performance. Some techniques include napping and bright light exposure. Common substances used for fatigue countermeasures include caffeine, melatonin, and hypnotic drugs.

1. Napping

Napping is used as a tool to improve human performance and efficiency. The time of day and the length of a nap are important factors in considering the usefulness and recuperative benefit of a nap (Naitoh, Tamsin, & Babkoff, 1991). Sleep inertia, the period after an individual awakens when he or she feels drowsy, confused, and/or unmotivated, is a serious concern when considering the utility of naps (Naitoh et al., 1991).

Napping prior to or during shiftwork, especially night work, improves alertness (Purnell, Feyer, & Herbison, 2002). Studies show that naps of 20–50 minutes, executed in the early portion of a night shift, improve reaction time and alertness (Purnell et al., 2002). In order to avoid sleep inertia, while also receiving some recuperative benefits, naps should not exceed 50 minutes and be no shorter than 10–15 minutes (Purnell et al., 2002). Additionally, a laboratory experiment conducted by Schweitzer, Randazzo, Stone, Erman, and Walsh (2006) simulating four nights of shiftwork concluded that napping improved both performance and alertness.

Over a period of several years during the late 1980s and early 1990s, researchers at NASA-Ames Research Center conducted a multidisciplinary study of fatigue on transmeridian flight crews (Dinges et al., 1991). The goal of the study was to assist in combating inadequate sleep as a major source of fatigue for long-haul flight crews (Graeber, Lauber, Connell, & Gander, 1986; Rosekind, Connell, Dinges, Rountree, & Graeber, 1991). The experiment involved rotating crew members through 40-minute naps while in-flight. The findings indicated that

although the naps failed to eliminate the cumulative sleep debt of the crew members, they improved crew alertness during flight and provided temporary relief from fatigue while in flight. The benefits were most apparent during night flights (Rosekind et al., 1994).

Sleep inertia hinders performance following naps. Naitoh et al. (1991) found that inferior logical reasoning remained for a 6-minute period following a 20-minute nap. Additionally, this study found that sleep inertia worsened as the amount of sleep debt increased, but that sleep inertia severity was not dependent upon the time of day (Naitoh et al., 1991). Thus, the severity of sleep inertia following naps did not change based on the time of day. Rather, the study discovered that the severity of sleep inertia depended on the stage of sleep from which the test subject was awakened (Naitoh et al., 1991). Furthermore, a study conducted by Dinges and Kribbs (1991) showed that there is a significant reduction in cognitive task performance during periods of sleep inertia.

2. Melatonin

The use of exogenous melatonin for improving circadian adaptation and treating CRSDs shows mixed results (Schaefer et al., 2012). Several studies point to the effectiveness of melatonin as a sleep aid. First, melatonin administered at certain desired times of the day can be helpful in accelerating a phase delay or phase advance. Second, when taken following a night of work, melatonin improves an individual's duration and quality of sleep (Schaefer et al., 2012). Using melatonin before daytime sleep to enhance night work alertness, however, has not been shown to be of significant benefit (Sharkey, Fogg, & Eastman, 2001).

3. Caffeine and Other Wake-Promoting Drugs

A multitude of studies exist demonstrating the effects of caffeine on reducing sleepiness, improving alertness, and enhancing cognitive ability (Schaefer et al., 2012). In one four-night laboratory study simulating night shiftwork, Schweitzer and colleagues (2006) found that caffeine improved both

alertness and performance. Modafinil, armodafinil, and other wake-promoting drugs, are actively prescribed by the medical community to treat SWD (Czeisler, Walsh, Wesnes, Arora, & Roth, 2009). Taken 30–60 minutes before the start of a night shift, these drugs have been shown to enhance performance and reduce sleepiness (Czeisler, Walsh, Roth, et al., 2009).

4.   Bright Light Exposure

Bright light exposure and concealment can improve circadian alignment, mood, and performance. A study conducted by Cajochen, Zeitler, Czeisler, and Dijk (2000) demonstrated that light exposure of 2,500–10,000 lux during the night shift greatly enhances alertness and performance; however, this enhancement does not reach daytime levels of alertness. Another study showed that circadian adjustments are improved for groups exposed to bright lighting while working at night and kept in darkness during the morning following night work (Eastman, Stewart, Mahoney, Liu, & Fogg, 1994). In his master's thesis at the Naval Postgraduate School, Lieutenant (LT) John Nguyen found that sailors working topside (i.e., exposed to sunlight) received less sleep and their sleep was more fragmented than personnel working below decks (i.e., not exposed to sunlight). One explanation he proposed for this difference was light exposure restricting the release of melatonin prior to sleep (Nguyen, 2002).

G.   MISHAPS CAUSED BY FATIGUE

This section aims to highlight three catastrophic disasters that occurred as a result of sleep deprivation: Chernobyl Reactor 4, *Exxon Valdez*, and Three Mile Island Unit 2. All three of these incidents happened during the night shift when people are more likely to feel fatigued and are at their circadian nadir. Thus, as a result of reduced cognitive ability, personnel in key positions made poor decisions, ultimately leading to tremendous public safety hazards and environmental damage.

1. Chernobyl Reactor 4

Chiles (2002) describes the accident at Chernobyl Reactor 4. Shortly after midnight on April 26, 1986, the V. I. Lenin Chernobyl Power Station Reactor 4, located on the Pripyat River 80 miles north of Kiev, Ukraine, suffered several massive explosions and a meltdown of its radioactive core. As the crew shut down the reactor that night in preparation for an annual maintenance period, they attempted to carry out a complex experiment. As the reactor was being shut down, their goal was to test the plant's ability to provide electrical power long enough to allow diesel generators to pick up the electrical loads. Unfortunately, in order to conduct this test, multiple automatic safety shutdown systems were disabled, thereby violating safety rules. These procedural violations allowed the reactor to operate in a condition for which it was not designed. Furthermore, the operators did not account for the intrinsic power that remained in the reactor as a result of operating continuously for the previous year. Thus, the experiment became increasingly difficult to continue, finally leading operators to panic and insert the control rods in an attempt to shut down the reactor. Regrettably, the graphite-tipped control rods stuck, causing the reactor's power to spike. Consequently, the water in the reactor turned to steam, causing a massive explosion in the containment facility. A subsequent explosion involved the melting reactor core itself. The explosions and melting core released two hundred times the amount of radioactivity into the atmosphere as the two atomic bombs dropped on Japan during World War II (Chiles, 2002).

2. Exxon Valdez

Skinner and Reilly (1989) describe the *Exxon Valdez* oil spill. Four minutes after midnight on Good Friday morning, March 24, 1989, the *Exxon Valdez*, a two-year old, single-skin, oil tank ship, ran aground on Bligh Reef in Prince William Sound, Alaska. During the days leading up to the accident, the ship's crew was routinely working 14-hour days, causing severe fatigue. The third mate, in particular, faced an excessive workload and suffered from severe sleep

debt as a result. Furthermore, Captain Hazelwood, in command of the *Exxon Valdez*, was intoxicated at the time of the mishap. While navigating the Prince William shipping lanes, the ship encountered chunks of floating ice. The Captain adjusted the ship's course accordingly and notified the U.S. Coast Guard Vessel Traffic Service (VTS) that the ship was going to exit the outbound traffic lane in order to so. Following this, the Captain ordered the weary Third Mate to turn the ship back into the outbound lane when abeam of Busby Island. He then exited the bridge, even though the turn was less than two minutes away. The Third Mate ordered the turn; however, the ship did not initially turn, but continued through the separation zone and the inbound traffic lane, eventually exiting the shipping lanes altogether. Unfortunately, the Third Mate did not notice that the ship failed to turn upon his order and went to the chart room to plot the turn. As a result, shortly after midnight, near the circadian nadir of the already exhausted Third Mate, the *Exxon Valdez* ran aground on Bligh Reef, spilling 258,000 barrels of crude oil in Prince William Sound, resulting in catastrophic environmental damage. The National Transportation Safety Board (1990) estimated that the cleanup during 1989 cost $1.85 billion (Skinner & Reilly, 1989)

3.   Three Mile Island Unit 2

Chiles (2002) describes the accident at Three Mile Island Unit 2. In the early morning of March 28, 1979, the reactor core of Three Mile Island Power Plant Unit 2, near Harrisburg, Pennsylvania, came within 30 minutes of meltdown. The incident cost General Public Utilities and the U.S. government more than $4 billion, the nation's most expensive industrial disaster at the time. A night (2300–0700) maintenance crew was attempting to clean a large water filter in the reactor coolant system; a routine operation. During this particular time, however, a few ounces of water escaped into the compressed air lines. Ultimately, this leak caused the automatic controls to shut valves that let coolant through. Shutting the valves caused a pipe to be torn loose, spraying high-temperature water throughout the controls in the turbine room. This event, however, was only the beginning of the problem (Chiles, 2002).

The reactor automatically shut down because heat could no longer be removed due to the shutting of the coolant valves (Chiles, 2002). This automatic action drastically reduced heat production in the core; however, temperature and pressure continued to rise as the water expanded. Nonetheless, the reactor system continued to operate as designed. The water expanded into the only place it could go, the pressurizer tank. Once the pressure increased too much, the pilot-operated relief valve (PORV) opened as designed to reduce pressure in the reactor coolant system by releasing steam to the containment building. When pressure stabilized within a few seconds, the PORV received the electronic signal to shut. Unfortunately, the PORV became stuck in the open position. In the control room, the proper indications for the PORV receiving the signal to both open and shut were observed by the operators. The operators, however, falsely interpreted the indication that the PORV had received the signal to shut as the valve actually shutting. The electronic command to shut had been sent to the valve, but the valve malfunctioned and remained stuck in the open position. The indication in the control room was that it operated as intended, although the PORV did not. For the next two hours, operators failed to notice that the PORV was stuck open due to lack of indications in the control room and a lack of knowledge regarding this specific casualty. They continued to follow procedure, but pressure continued to drop while the water level in the pressurizer continued to rise (Chiles, 2002).

At 0600, a well-rested supervisor arrived and, within 15 minutes, had developed two theories for the current problem (Chiles, 2002). His first theory was that a blown circuit breaker disabled electric heaters in the pressurizer. His second theory was that a small leak existed in the reactor coolant system. He investigated the leak, while another worker looked into the potential blown breaker. After verifying multiple control room indicators, the more alert operator shut an isolation valve leading to the stuck open PORV. As a result, pressure began to rise and the water level stabilized, avoiding a complete meltdown (Chiles, 2002).

H. SLEEP AND FATIGUE ANALYSIS QUESTIONNAIRES

The sleep analysis questionnaires described in this section are the Pittsburgh Sleep Quality Index (PSQI), Epworth Sleepiness Scale (ESS), and the Composite Scale of Morningness (CSM). Each is a self-administered questionnaire that can be completed on paper or electronically. The three questionnaires are validated and accepted throughout the sleep and fatigue community. See Appendices C, D, and E for copies of the PSQI, ESS, and CSM, respectively.

1. Pittsburgh Sleep Quality Index

The PSQI, developed in the late 1980s, is a validated, self-rated questionnaire that evaluates sleep quality and disturbances over a one-month period of time (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989a). The questionnaire consists of 19 individual items that are combined to produce seven component scores. The seven component scores are: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The sum of the seven component scores yields a global score. Based on the global score, individuals are classified as either having "good" sleep quality or "poor" sleep quality. The PSQI takes 5–10 minutes for a subject to complete and five minutes to score, and is available in 57 different languages (Buysse et al., 1989a).

According to Buysse et al. (1989a), the PSQI is a useful tool for determining sleep quality. First, it offers a reliable, validated, and standardized measure of sleep quality. Second, the PSQI distinguishes between "good" and "bad" sleepers. Third, it provides an index that is simple enough for subjects to fill out, yet robust enough to provide clinicians and researchers with useful data. Fourth, PSQI delivers a brief, but useful, evaluation of a multitude of sleep disturbances that may affect sleep quality. Finally, the only limitation of the PSQI is that, as a self-rated and subjective means of determining sleep quality,

possible inaccuracies are introduced due to erroneous information being provided by subjects (Buysse et al., 1989a).

The questions that make up the PSQI came from three sources: clinical intuition and experience, a review of previous sleep quality questionnaires, and an 18-month-long field testing period (Buysse et al., 1989a). The 19 self-rated questions assess a variety of factors affecting sleep quality. Specifically, estimates of sleep duration and latency, as well as the frequency and severity of specific sleep-related problems, are evaluated. The 19 individual items, each weighted equally from 0 to 3, are assembled into seven component scores. Then the sum of the seven component scores yields a global PSQI score. This score can range from 0 to 21. Higher scores designate worse quality sleep (Buysse et al., 1989a).

2.   Epworth Sleepiness Scale

The ESS is a validated, self-administered questionnaire developed by Dr. Murray Johns (1991a) that provides a measurement of an individual's overall daytime sleepiness. The ESS consists of eight questions scored on a four-point (0 to 3) scale. The total ESS score is the sum of the scores from the eight questions, with a possible range of 0 to 24. Higher scores represent a higher level of daytime sleepiness. The questions ask the subject to rate their usual chance of dozing off or falling asleep in eight different, but routine, activities that most people participate in as a part of daily life. The ESS takes approximately 2–3 minutes to complete (Johns, 1991a).

The specific questions that comprise the ESS were chosen *a priori* by Dr. Johns (1991a), based on their somnificity. In other words, the questions were chosen based on the capacity of an activity to facilitate sleep-onset in a majority of subjects based on posture, activity, and situation. Individuals are much more likely to doze off while engaged in activities of high somnificity (e.g., Item 5 of the ESS is "lying down to rest in the afternoon when circumstances permit") than while participating in activities of low somnificity (e.g., Item 6 of the ESS is "sitting

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and talking to someone"). Therefore, a higher ESS score indicates a higher average sleep propensity, thus signifying a higher chance of falling asleep during activities of low somnificity. ESS scores greater than 10 are classified as abnormal, while scores less than or equal to 10 are classified as normal (Johns, 1991a).

According to Johns (1991a), the ESS is a useful tool for determining individuals' daytime sleepiness levels. First, the test, consisting of only eight rather easy-to-answer questions, is simple and only requires minutes to complete. Second, the ESS score provides a measure of a subject's average sleep propensity (ASP), for which there is no other objectively accepted "gold standard" for doing so. Third, ESS scores are reliable in regards to retesting subjects over a period of several months. Fourth, the ESS serves as an indicator of possible sleep-related problems such as sleep disorders or sleep deprivation (Johns, 1991a).

According to Johns (1991a), the ESS has several limitations. First, the questions require subjects to retrospectively and subjectively assess their own likelihood of dozing off while engaging in different activities. This process introduces inaccuracies into the data due to the possibility of subjects erroneously answering the questions. Second, it is not suitable for measuring rapid alterations in sleep propensity over a short period of time (i.e., hours). Third, ESS does not provide any diagnostic capability, in that it can only be used as a tool for indicating possible problems with a person's sleep-wake cycle. Fourth, ESS scores do not correlate very closely to their mean sleep latency as determined by the Multiple Sleep Latency Test (MSLT), the most widely accepted measurement of sleepiness (Johns, 1991a).

Based on the results of a study conducted on a deployed U.S. Navy destroyer, Shattuck and Matsangas (2014) have shown that the ESS possesses utility in predicting PVT performance for naval personnel in an operational setting. Participants wore wrist activity monitors, completed sleep and activity logs over an 11-day period, and completed the ESS immediately preceding the

data collection period. PVTs were administered throughout the data collection period. The study determined that within the population studied, the ESS classification seems to be an effective tool for identifying individuals that may be at risk for degraded PVT in operational settings (Shattuck & Matsangas, 2014).

3. Composite Scale of Morningness

The CSM is a widely used and accepted measure of behavioral temporal predilection. With validated versions existing in four languages (English, French, Thai, and Italian), the CSM is currently the best subjective method for determining individuals' chronotype. The three types currently accepted within the literature are referred to as morning (larks), intermediate (robins), and evening (owls).

The CSM was developed in 1989 by Smith, Reilly, and Midkiff. Their original intent was to develop a better tool for selecting the most suitable personnel for shiftwork (Smith et al., 1989). The scales previously created possessed questionable psychomotor properties and were either too long or too short. Thus, Smith et al. (1989) used the best combination of questions from the Morningness-Eveningness Questionnaire (MEQ) and the Diurnal-Type Scale (DTS) created in 1976 and 1980, respectively. The CSM, consisting of 13 items, has since been validated and its reliability verified through follow-on studies (Morales & Sanchez-Lopez, 2004). CSM scores can range between 10 and 56. The score ranges for evening, intermediate, and morning types are 10–22, 23–43, and 44–56, respectively.

I. MODELS OF HUMAN PERFORMANCE AND FATIGUE

This section provides brief descriptions of several models of human performance, sleep, and fatigue. Each model was developed for different uses and groups. For example, the SAFTE model was first developed for the Department of Defense (DOD), while the three-process model was designed for schedulers and planning staffs.

1.   Three-Process Model

Folkard and Akerstedt (1992) designed the three-process model. The model was developed for the use of schedulers and planners responsible for assessing fatigue and performance effects of schedules. Other users include those interested in studying performance in relation to irregular work hours. The three-process model is nearly the same as the two-process model, except that that it has an additional process, called Process W. Process W represents sleep inertia and the waking-up process, which is not represented in the two-process model. The software allows for the following inputs: bedtime and sleep termination times, times of sleep, change in time zones, diurnal types, sleep length, and sleep problems. The primary output is a predicted alertness curve (Folkard & Akerstedt, 1992).

2.   Fatigue Audit InterDyne Model

According to the Roach, Fletcher, and Dawson (2004), the fatigue audit interDyne (FAID) model, developed at the University of South Australia's Center for Applied Behavorial Science, can be used to quantify work-related fatigue associated with any duty schedules using hours of work. Utilizing the three-process model, the sole inputs are the start and end times of work periods. Schedules are modeled as a square wave function between work and non-work. Work-related fatigue is linearly related to the length of the work period, while non-work related recovery is related to the circadian rhythm with a sinusoidal wave. There is also a weighting factor, or recency component, that places an emphasis on recent work or recent nonwork periods. The output of FAID is a generic variable representing fatigue that results from an overall fatigue score that is generated by an algebraic function of work and nonwork weighted by the recency component (Roach et al., 2004).

3.   Circadian Alertness Simulator Model

Moore-Ede and Mitchell invented and patented the circadian alertness simulator (CAS) model as a practical tool for assessing the risks of fatigue in the

24/7 workplace (e.g., the railroad industry) in 1995. The ultimate goal of the model is reduce the rate of injuries and deaths caused by fatigue-related workplace accidents (Moore-Ede et al., 2004). The CAS can be used to assess operational fatigue risk, work schedule optimization, and fatigue-related accident investigation (Moore-Ede et al., 2004).

Using the basic Two-Process Model, employee work schedules are inputs into the model and sleep alertness patterns are estimated. Process S of the Two-Process Model is modeled as an exponential function that increases during sleep and decreases during wakefulness (Moore-Ede et al., 2004). Thus, the model assumes that recovery during sleep occurs exponentially, implying that the first several hours of sleep contribute more to recovery than the last few hours (Dijk & Larkin, 2004). This simplifying assumption may help explain the failure of many current models in predicting fatigue resulting from chronic partial sleep deprivation (Dijk & Larkin, 2004). Process C is modeled with a 24-hour sinusoidal wave function. The output is a calculated cumulative fatigue score resulting in a minute-by-minute, continuous alertness curve for the time period of interest. Statistics related to sleep, work, and alertness are provided in a table or graph, which provides for easier analysis. One drawback of the CAS Model is that even though it is designed to predict alertness for individuals, it is not biometrically or psychometrically individualized. Only "morningness" or "eveningness," and a person's age, can be input as trait variables (Dijk & Larkin, 2004).

4.   Sleep, Activity, Fatigue, and Task Effectiveness Model

The SAFTE model is a biomathematical fatigue model that was introduced in 1996, updated in 2002, and patented in 2003. Hursh, a renowned research psychologist and career Army officer, developed the SAFTE Model while working at Scientific Applications International Corporation (SAIC). It was, however, a truly joint effort among multiple DOD laboratories and independent corporations throughout the United States, spanning over two decades, that helped develop the SAFTE Model into what is today. The U.S. Army's groundbreaking sleep

deprivation and performance research at the Walter Reed Army Institute of Research (WRAIR), at which Hursh was the director of the Neuropsychiatry Division, paved the way for the evolution of the SAFTE model (IBR Inc., 2014). Other contributing laboratories included the Naval Health Research Center (NHRC), the Air Force Research Laboratory (AFRL), and the U.S. Army Aviation Research Laboratory (USAARL). Corporations, such as SAIC and NTI, Inc., also contributed key technical resources and manpower to the development of the SAFTE model and its implementation (Hursh, 2010). Subsequently, Hursh developed software packages known as the FAST and later SAFTE-FAST to provide user-friendly, stand-alone computer programs that allowed SAFTE to be applied to real-world scenarios.

a.   *Background*

While representing the Army Medical Research and Development Command, later redesignated as the Medical Research and Materiel Command (MRMC), Hursh supervised the development of the first model capable of modeling the effect of sleep deprivation on Army unit effectiveness during the latter stages of his Army career (Hursh, 2010). The Army Unit Resilience Analysis (AURA) program, developed by the Ballistics Laboratory at Aberdeen Proving Grounds, provided the initial modeling platform for this ground-breaking research. Although, the code was enormous, through the efforts of computer programmers at SAIC and by building on initial fatigue code developed by Klopcic in 1989, which was subsequently translated into a FORTRAN computer program by McNally, the model allowed for relatively easy experimentation by 1993. Overall, the model demonstrated that the productivity of Army artillery units was maximized following eight hours of sleep (Hursh, 2010). Unfortunately, this model was eventually abandoned based on fundamental contradictions and laboratory results on chronic sleep restriction at WRAIR (Belenky et al., 2003). Nevertheless, the success of this model as an instrument for translating fatigue research results into operational efficiency measurements laid the groundwork

for additional research and modeling that led to the development of the SAFTE Model and other efforts that continue today.

After retiring from active duty in 1995, Hursh joined SAIC to head their biomedical modeling and analysis program (Hursh, 2010). It was during his time at SAIC that he developed the initial version of the SAFTE Model. While working under contract for the WRAIR, Hursh built on a long tradition of WRAIR sleep and fatigue research dating back to the 1950s. His task now, however, was to construct a model that could be built into a wrist-worn activity monitor capable of providing soldiers and unit leaders with instantaneous feedback in regards to soldier performance capability (Hursh, 2010). Following meetings with WRAIR scientists, Belenky and Balkin and Hursh and his team realized that the original AURA Model possessed a fatal flaw. This realization proved crucial for subsequent fatigue modeling. The flaw was that if someone lacked the required eight hours of sleep per day, he or she would eventually "exhaust their performance resources and degrade to zero effectiveness" (Hursh, 2010, p. 50). Since little laboratory evidence supported otherwise, sleep experts at the time believed that, while restricted sleep reduced performance, equilibrium would be reached at some point, preventing performance from reaching zero (Hursh, 2010). The goal now was to construct a model that incorporated the equilibrium theory (Hursh, 2010).

The main challenge in developing a robust fatigue model was a lack of necessary data (Hursh, 2010). An abundance of data on both baseline performance of fully rested individuals and performance of completely sleep-deprived individuals (up to 84 hours of sustained wakefulness) existed. Unfortunately, information on "sleep doses" between eight and zero hours per day, the essential data required for developing fatigue models, was nearly nonexistent (Hursh, 2010). All fatigue modelers at the time were forced to interpolate between the two extremes, while also being provided little guidance on the consequences of partial sleep deprivation and sleep restriction. From the

realization of this vital knowledge gap, emerged a field of research focusing on the effects of patterns of sleep deprivation on cognitive performance (Hursh, 2010).

During the winter of 1996, Hursh constructed the basic mathematical structure of a fatigue model that eventually became the WRAIR sleep and performance model (SPM) (Hursh, 2010). This original model, although altered and upgraded many times, started out as a simple spreadsheet calculator. Significantly, similar to other physiological processes, this fatigue model was homeostatic (Hursh, 2010). Delivered to the Army in the spring of 1997, the model was implemented in a wrist activity monitor that detected and scored sleep, calculated performance effectiveness, and provided immediate feedback to the soldiers through a visual display. WRAIR SPM was validated against data from several WRAIR and other independent laboratory studies, in which it was found to have "surprising generality and utility" (Hursh, 2010, p. 51). From SPM evolved the SAFTE Model.

b.   SAFTE Model Description

SAFTE is a three-process, quantitative biomathematical simulation similar to those developed by Folkard and Akerstedt (1987), Achermann and Borbely (1992), Akerstedt and Folkard (1995), and Jewett and Kronauer (1999). A conceptual architecture of the SAFTE model is presented in Figure 7. SAFTE combines the effects of sleep pattern, time of day, and sleep inertia. A circadian process influences both performance and sleep regulation. Sleep regulation (homeostatic sleep drive) is a function of hours of sleep, hours of wakefulness, current sleep debt, the circadian process, and fragmentation or awakenings during a period of sleep resulting from a poor-quality sleep environment (IBR, Inc., 2014). Performance is a function of the current balance of the sleep regulation process, the circadian process, and sleep inertia. Furthermore, available actigraphy data from wrist activity monitors continue to be a major source of sleep information to drive the model (IBR, Inc., 2014).

Schematic of SAFTE Model
Sleep, Activity, Fatigue and Task Effectiveness Model
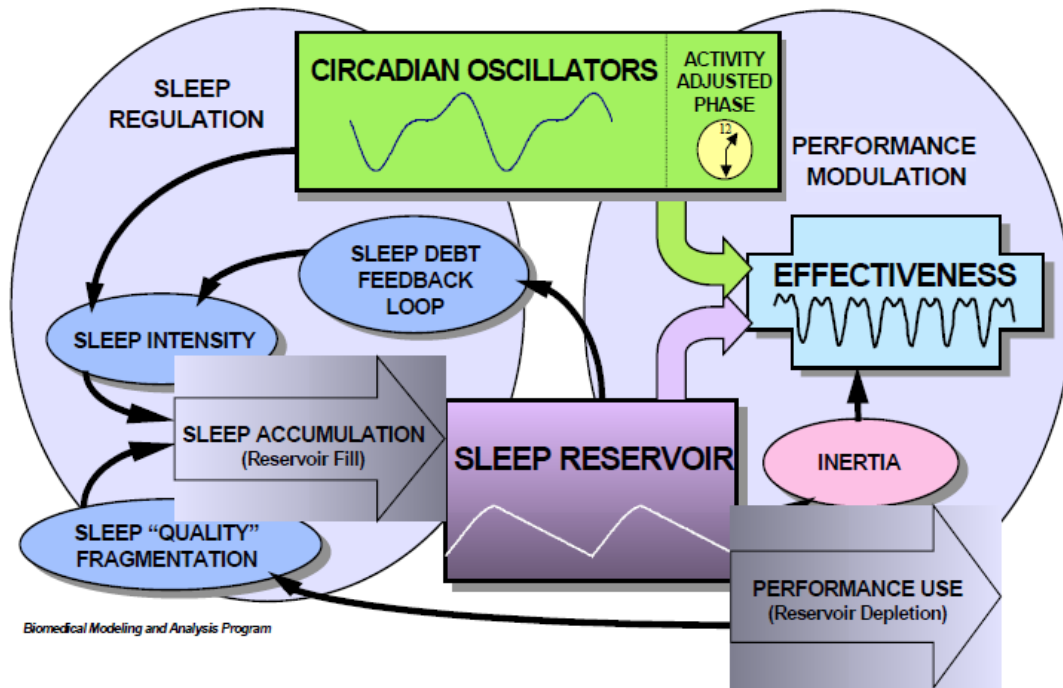
Figure 7.   Block Diagram of the SAFTE Model (from Hursh, Redmond et al., 2004, p. A44).

SAFTE is applied to hypothetical or prospective work and sleep schedules as a means of discovering performance decrements. Furthermore, it is used to optimize operational planning and management (Hursh, Redmond et al., 2004). Originally designed with the three-process model, the SAFTE model was embellished with a fourth process that modulates the sleep reservoir capacity during chronic sleep restriction. This accounts for slower-than-expected rebound of performance after recuperative sleep. Additionally, SAFTE accounts for circadian shifts as a result of transmeridian travel and shiftwork schedules (Hursh, Redmond et al., 2004).

At the core of SAFTE is a "sleep reservoir," maintaining a balance of effective performance "units." The variation in reservoir level models the

homeostatic regulation of sleep. Performance capacity is equivalent to Process S. Process C models the influence of circadian rhythms in sleep-wake regulation. Process W models sleep inertia (Hursh, Redmond et al., 2004). When an individual is fully rested in optimal conditions, he or she has a finite, maximum performance capability (Hursh, Redmond et al., 2004).

While awake, the sleep reservoir contents are depleted and while asleep the contents of this reservoir are replenished (Hursh, Redmond et al., 2004). Sleep accumulation is based on sleep quality and intensity. Going one step further, sleep intensity is controlled by the circadian process (i.e., factors in the time of day that sleep is acquired) and the current contents of the reservoir (sleep debt) (Hursh, Redmond et al., 2004).

Sleep quality is judged based on continual or fragmented sleep as determined by real-world demands and requirements to perform (Hursh, Redmond et al., 2004). Sleep fragmentation is modeled by inserting a penalty for sleep interruptions. The output of the SAFTE Model is predicted effectiveness, which differs depending on the circadian effects and the reservoir level. Sleep inertia is also modeled in order to capture the temporary performance decrements immediately upon awaking from sleep (Hursh, Redmond et al., 2004).

c.   *Limitations and Advantages*

The SAFTE Model possesses several key limitations. First, with the exception of "morningness/eveningness" preference, the physiological fatigue model is the same for all personnel. In other words, individual sleep needs are not yet incorporated into the model. If individual sleep need data becomes easier to obtain in the future, however, a factor accounting for it could be added to the model (IBR, Inc., 2014). Second, it does not estimate group variance of the average performance prediction (IBR, Inc., 2014). An additional limitation is the inability to predict the effects of stimulants (e.g., caffeine and d-amphetamine) used for extending performance or sedatives (e.g., melatonin and prescription

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sleep aids) for enhancing sleep (IBR, Inc., 2014). These considerations are of particular interest for military operations, where pharmacological countermeasures are regularly used for performance enhancement. Additionally, the following factors are not accounted for: parametric environmental sleep quality, workload and time-on-task, and environmental performance shaping functions (such as heat, motion, etc.) (Hursh, 2014; Hursh, Redmond et al., 2004). The myriad of lessons from real-world operations and additional research since the development of the SAFTE Model are not yet fully incorporated into the model (Hursh, 2014). Sleep and wake are considered completely separate and absolute states. In other words, with the exception of a factor accounting for the quality of one's sleep environment, the dynamic nature of sleep and wakefulness are not accounted for in the model. Finally, circadian modulation and circadian phase are, as Hursh describes, "hard-wired" into SAFTE's algorithm (Hursh, 2014).

Even with its limitations, SAFTE is the world's leading sleep and fatigue model (Hursh et al., 2004; IBR, Inc., 2014). Although the underlying mathematical model structure is conceptually similar to others proposed and accepted before SAFTE's development, the current version takes advantage of advancements and research made in the last decade and a half. Some of the most important enhancements include the incorporation of prolonged sleep restriction and recovery from sleep loss (Hursh et al., 2004; IBR, Inc., 2014). The SAFTE Model was validated against laboratory results in 2002 and subsequent operational studies through work with the Federal Railroad Administration (FRA) and commercial airline industry and the Federal Aviation Administration (FAA). Detailed descriptions of the model are published and peer reviewed (Hursh et al., 2004; IBR, Inc., 2014). When independently evaluated against all other available sleep and fatigue models, SAFTE performed with the least amount of error of any model under the conditions of partial sleep deprivation, which is characteristic of sustained military operations (Van Dongen, 2004).

d.   Key Features

The SAFTE Model, as implemented in the SAFTE-FAST software, has several essential capabilities not included in any prior models (the SAFTE-FAST software is discussed more in depth in the next section). Most notably, SAFTE-FAST is optimized to predict changes in cognitive performance, as opposed to only alertness (IBR, Inc., 2014). It predicts the decline in sleep intensity over a period of sleep. SAFTE is able to incorporate the deleterious effects of sleep fragmentation and multiple sleep interruptions (Hursh & Bell, 2001). By utilizing a multi-oscillator (sum of two cosine waves) model for the circadian process, SAFTE is able to incorporate the 24-hour asymmetrical cycle of performance. Thus, it can predict the performance nadir associated with the early morning hours and the performance drop associated with the midafternoon hours of the day. Circadian variations in sleep quality, limitations on performance under schedules that require daytime sleep, sleep inertia, transmeridian travel effects (i.e., jet lag), and shiftwork can also be predicted (Hursh & Bell, 2001).

The SAFTE-FAST model performs well in operational environments due to three vital components. First, the *AutoSleep* algorithm estimates potential patterns of sleep based on the opportunities to sleep provided by an individual's work schedule and activities (IBR, Inc., 2014). The ability to estimate sleep and performance is particularly useful in military operational environments, where direct measurement of sleep is not always available. Furthermore, the *AutoSleep* feature can be used in conjunction with actigraph-monitored sleep measurements when possible. Several studies by the FRA demonstrated that, based on wrist-worn activity monitors, *AutoSleep* is 87% accurate in predicting actual sleep patterns and came within seven minutes of calculating average sleep per day for train crews (IBR, Inc., 2014).

The second essential component is a feature that accounts for the long-term effects of sleep restriction. Based on laboratory studies conducted at WRAIR, demonstrating the long-term effects of sleep deprivation and the resultant slow recovery, SAFTE was updated to account for such effects (IBR,

Inc., 2014). SAFTE accounts for approximately 94% of the variance in average performance observed in laboratory studies (IBR, Inc., 2014).

The third fundamental element is algorithm logic that adjusts the circadian phase of individuals based on changes in sunlight exposure, sleep timing, and time zones (IBR, Inc., 2014). The model's ability to account for the dynamic nature of humans' circadian rhythms is particularly important for individuals that regularly rotate their sleep and work times throughout all hours of the day, such as Navy watchstanders at sea. The tremendous power of the SAFTE model is best summarized as follows:

> The combination of the validated SAFTE biomathematical model with three additional algorithms in FAST confer important advantages to the SAFTE-FAST system compared to all other fatigue modeling systems for the prediction of operational risk. (IBR, Inc., 2014, p. 5)

The SAFTE model is particularly useful in military applications. SAFTE was tested using empirically-derived data with outstanding predictive accuracy, especially for chronically restricted amounts of sleep. In fact, using data from a WRAIR study of chronic sleep deprivation, they obtained a R^2 of 0.94 (Hursh, Balkin, Miller, & Eddy, 2004). The DOD selected SAFTE from other competing fatigue and performance models as the most complete, accurate, and operationally practical model (Hursh, Balkin, Miller, & Eddy, 2004). It is now the model of choice for DOD operational planners and schedulers.

J.   FAST AND SAFTE-FAST COMPUTER SOFTWARE

FAST is the software that incorporates the SAFTE Model. The U.S. Air Force first implemented the model as a user-friendly stand-alone computer program through the use of FAST in 2000. The FAST software was developed through parallel efforts at Brooks Air Force Research Laboratory, WRAIR, NTI, and SAIC. Yet, due to additional investment from the Department of Transportation, the SAFTE model and FAST continued to be enhanced, culminating in the current version of the model and software known as SAFTE-

FAST (Hursh, 2010). As of today, SAFTE-FAST is a Windows-based software package designed to tabulate and graphically display patterns of cognitive performance changes over a period of time and estimate factors affecting fatigue during any point in an actual or hypothesized schedule (IBR, Inc., 2014).

1. FAST

FAST is a user-friendly software program designed for use by operational planners and schedulers. Using FAST, predicted effectiveness can be ascertained for periods of up to several months. For military operations specifically, FAST provides planners with the capability to optimize performance under conditions of limited sleep and minimizes the need for pharmacological aids (Hursh, Balkin et al., 2004).

FAST integrates many interpretive tools for visualizing performance changes over a period of time. Multiple schedules can be compared on the basis of predicted changes in cognitive capacity. The user can easily view the effects of preprogrammed and user-defined sleep/wake schedules on predicted performance capability (Hursh, Balkin et al., 2004). The user interface enables rapid visual and quantitative estimates of how various factors affect individual cognitive performance. These tools provide users flexibility by allowing preprogrammed sleep schedules to be uploaded, edited, and saved, while also allowing for user-defined schedules to be uploaded from external programs, then edited and saved in FAST (Hursh, Balkin et al., 2004). In addition, actigraphy data from wrist activity monitors previously worn by test subjects can be uploaded into FAST to determine their predicted levels of effectiveness over a time period of interest (Hursh, Balkin et al., 2004).

One of the most interesting FAST outputs is effectiveness. The model predicts effectiveness, which validation studies have shown is directly related to the percent change in reaction time on a PVT (IBR, Inc., 2014). The possible effectiveness score can range from 0 (unable to perform) to 100 (typical of a well-rested human). Normal variation of effectiveness of a well-rested person

throughout a normal workday is between 90 and 100. As shown in Table 3, effectiveness continues to decline as the number of hours of sustained wakefulness increases. IBR, Inc. recommends closer examination of all effectiveness levels less than 77.5, especially if they are related to excessive sleep debt. Below this level, the Air Force uses countermeasures to improve performance (IBR, Inc., 2014).

Continuous Hours of Wakefulness	Effectiveness (% of Baseline)	Reactime Time (% increase from Baseline)	Lapse Likelihood (relative to 1 for a well rested)	Equivalent BAC
16	90	11	1.5	NA
18	80	25	3.1	< 0.05
18.5	77	30	3.7	0.05
19	75	33	4	> 0.05
21	70	43	5.2	0.08
40	65	54	6.5	> 0.08

Table 3.   Relates continuous hours of wakefulness to FAST's predicted effectiveness, reaction time, lapse likelihood score, and an equivalent Blood Alcohol Content (BAC). The increase in the hours of wakefulness is nonlinear due to circadian interactions (after IBR, Inc., 2014, p. 18).

FAST's visual effectiveness graphic is an extremely useful feature. Performance predictions are displayed in user-selectable intervals ranging from 6 hours to 30 days. A blood alcohol scale is provided to show how the effects of fatigue are comparable to alcohol intoxication, making the predicted results more easily interpretable by the user. A lapse index is provided that displays the likelihood that an individual will miss critical information. Finally, the "Dashboard" feature allows the user to interrogate any minute of data from the graphical display. Within the Dashboard pop-up window, five different fatigue factors, three alternative performance metrics, and the sleep reservoir level are displayed.

The example of the primary FAST user interface, as seen in Figure 8, has several useful features. The different bands of color (green, yellow, red)

represent adjustable thresholds of predicted performance. Green represents a predicted effectiveness of 90% or better; yellow represents 65%–90% effectiveness; and red represents predicted effectiveness below 65%.
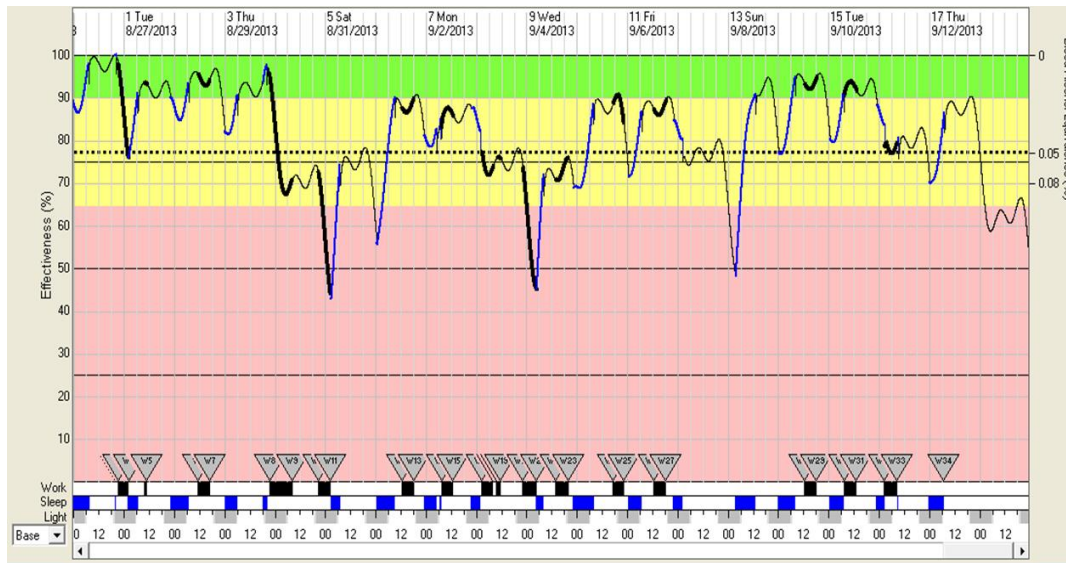

Figure 8.   FAST plot generated using FAST version 2.9.04G_T (after NTI, Inc. & SAIC, 2012).

The vertical axis on the right can be set to four different scales: blood alcohol content equivalence, lapse index, sleep reservoir level, or acrophase. Setting the right vertical axis to a blood alcohol equivalence scale allows for direct comparison of the effects of alcohol intoxication to the effects of fatigue based on empirical studies conducted by Dawson and Reid (1997). Lapse index refers to a prediction of the likelihood of an individual experiencing a lapse or excessively long reaction time associated with "micro-sleeps" (IBR, Inc., 2014). For example, a lapse index of 2 means that a person is twice as likely to experience a lapse as a normal, well-rested person during an average day (IBR, Inc., 2014). Acrophase is the time of day at which a person reaches their circadian peak. In the SAFTE model, acrophase refers to the time at which the 24-hour component of the circadian rhythm reaches its peak (IBR, Inc., 2014).

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2.   SAFTE-FAST

Although the first aviation application of the SAFTE model was for the Air Force in 2000, the most advanced version of the SAFTE model, as implemented in SAFTE-FAST, has been optimized for the commercial airline and railroad industries (IBR, Inc., 2014). Commercial airlines started using SAFTE-FAST following substantial enhancements of the original SAFTE Model and FAST software. Currently, 22 commercial airlines, the Canadian and U.S. Air Forces, and 13 commercial railroads use SAFTE-FAST for operational planning and scheduling (IBR, Inc., 2014).

SAFTE-FAST incorporates all aspects of the FAST software with several important additions. The most significant capability enhancement is SAFTE-FAST's ability to handle nearly an unlimited number of schedules and batch process files input by the user for analysis. SAFTE-FAST uses one of two user-specified translators to process data. These translators are referred to as the shiftwork translator and aviation translator. Both translators are useful; however, the shiftwork option is designed for the rail industry, while the aviation translator is designed specifically for the aviation industry. The type and number of files required for conducting an analysis is dependent upon the translator selected by the user. The ability to batch process schedules significantly reduces processing time and the amount of "pointing and clicking" required of the user.

Although most of the inputs into SAFTE-FAST are similar to those for FAST, SAFTE-FAST has the capability to output more robust data. The three main outputs are the manager table, summary file, and the visual FAST graphic. The manager table provides a user-friendly interface for compiling useful performance indicators such as occurrences below a certain threshold, total time below a designated criterion level, and performance level during user input critical times. The summary file provides detailed information on effectiveness at the beginning and end of desired intervals, minimum sleep reservoir at critical times, and distributes time in 5% bins of effectiveness (IBR, Inc., 2014). The visual FAST graphic is the same as the graphical display shown in Figure 8.

K. PAST STUDIES OF U.S. NAVY AIRCRAFT CARRIER PERSONNEL SLEEP, FATIGUE, AND PERFORMANCE

There are two main studies concerning aircraft carrier personnel sleep, fatigue, and performance. The first study concerned the 1997 surge of the USS *Nimitz* (CVN-68) carrier strike group in support of Joint Task Force Exercise (JTFEX) 97-2. During the surge, the ship carried out four days of nearly continuous flight operations. The sleep data for this study was self-reported through surveys, while the performance and fatigue data was simply based on individuals' perceived feelings of fatigue and effectiveness. The second study was conducted on the USS *Stennis* by John Loc Nguyen of NPS from 1 to 4 February 2002, during which time the crew worked during the night and slept during the day in order to support night combat flight operations. Sleep data was collected via actigraphy wrist monitors. Individuals reported circadian adjustment via surveys. Body temperature was also collected.

1. USS *Nimitz* and Carrier Air Wing Nine Surge Demonstration

On 20 July 1997, as part of JTFEX 97-2, USS *Nimitz*, with Commander, Carrier Group Seven (CCG-7) and Carrier Air Wing Nine, commenced a high-intensity strike campaign. Over the next four days, they executed 771 strike sorties and put 1,336 bombs on target. The Center for Naval Analyses (CNA) supported CCG-7 in the assessment of data collected during the surge. All of the data was collected via personnel surveys. In all, 193 individuals participated in the study (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny, Hall et al., 1998).

The fatigue survey collected data on hours of sleep and individuals' perceptions of how well they were performing their jobs. The survey found that the more sleep an individual reported, the higher his or her rating of performance (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998). Three hours of sleep was found to be the critical value for personnel reporting satisfactory performance levels. In addition, sleeping longer than nine

hours appeared to do little for improving perceived performance (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998).

The study found little difference in self-reported sleep and performance between officer and enlisted personnel (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998). Aircrew members however, tended to report slightly more hours of sleep and higher estimates of performance. In addition, the catapult and arresting gear personnel received the least amount of self-reported sleep and held a much lower perception of job performance. This finding confirmed anecdotal evidence that this particular group of enlisted personnel was stressed much more than other groups during the intense flight operations schedule (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998).

The objective method used to measure personnel fatigue during the surge was via the FIT System. Designed by PMI Incorporated to identify at-risk workers for a broad range of impairments such as alcohol, drugs, stress, fatigue, and sleep deprivation, the FIT System stimulates the eye with pulses of light (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998). It then measures both the amplitude and response time of the involuntary eye reflexes (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998). The main conclusion reached as a result of the FIT tests was that the majority of personnel judged to be at high risk by FIT were older and had fewer hours of sleep, but they did not self-report having serious decrements in their job performance or mental state (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998). This finding supports other studies that show that as an individual's sleep debt increases, their ability to judge their performance and fatigue levels diminishes. The study did not draw any other serious conclusions from the FIT tests concerning sleep and performance (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998).

The most fatigued personnel during the surge appeared to be the highest-ranking individuals. The Commanding Officer of USS *Nimitz* and the S-3 (Sea Control-3) Squadron Commander averaged the least amount of sleep and assessed their fatigue to be at a much higher level than during normal operations (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998). In fact, the S-3 Squadron Commander was labeled untestable by the FIT fatigue test, perhaps because he was so fatigued even before the surge started. Most individuals, with the exception of personnel in command positions, troubleshooters, and the personnel on the Operational Strike Planning Cell (OSPC), reported that fatigue did not have a significant impact on their performance (Jewell, Wigge, Gagnon, Lynn, Kirk, Berg, Roberts, Hale, Jones, Matheny et al., 1998).

The major weakness of this study is that all sleep and performance data was based on self-reported surveys, which, unfortunately, allowed inaccurate and tremendously biased data to enter the analysis. Thus, any conclusions must be approached carefully if they are to be generalized. Without more accurate sleep data, such as that obtained by actigraphy wrist monitors, the actual amount of individual sleep is suspect. Furthermore, self-perceived job performance is even more suspect, especially when it is being studied during periods of extreme sleep deprivation and stress, such as during this study. Therefore, while important indicators, the performance data, analysis, and conclusions regarding performance during the surge must also be cautiously approached.

2. USS John C. Stennis

For his master's thesis at the Naval Postgraduate School, Nguyen (2002) analyzed the fatigue levels and sleeping patterns of sailors on the USS *John C. Stennis* for four days of an inverted work-rest schedule during combat operations. Actigraphy, oral temperatures, and subjective rating scales were collected on 33 personnel from 1 to 4 February 2002. The overall findings of his thesis concluded that significant differences exist in both the quantity and quality

of sleep among different groups of sailors. For example, personnel working topside received significantly less sleep, which was more fragmented than the sleep of personnel working below decks. One explanation Nguyen proposed for these differences was light exposure restricting the release of melatonin prior to sleep. Additionally, the study was able to show that the predicted effectiveness, as determined by FAST, was much more degraded for personnel working topside (Nguyen, 2002).

Nguyen (2002) provided several recommendations for commanders when adopting inverted sleep-rest schedules. First, commanders must be educated in regards to sleep deprivation and methods for combating sleep debt. Second, commanders must gradually phase in any operations that require personnel to adopt a reversed or near-reversed work-rest schedule. Specifically, work-rest schedules consisting of four hours on and four hours off should no longer be used because they prevent continuous sleep of at least 4.5-5.5 hours (Nguyen, 2002).

L.   THE NAVY STANDARD WORKWEEK

The NSWW is one of the tools used in determining manpower requirements for the Fleet. Workweeks for sea duty/operational units are determined by operational requirements based upon projected wartime conditions. Calculation of workweeks for shore units are based upon peacetime conditions. These workweeks are used by the Chief of Naval Operations (CNO) to document manpower requirements.

Essentially, the Navy standard workweek breaks a standard seven-day week (or 168 hours) into two different categories: available time and non-available time. Available time is calculated to be 81 hours, while the remaining 87 hours of time is non-available time (Chief of Naval Operations [CNO], 2011). For an afloat (wartime) unit, non-available time is calculated based on sleep, messing, personal needs, and free time. Of note, 56 hours is allocated for sleeping (8 hours per night), 14 hours for messing, 14 hours for personal needs,

and 3 hours of free time (CNO, 2011). Training (7 hours) and service diversion (4 hours) are included in the available time. Thus, 70 hours per week are allocated for what the Navy terms "Productive Work" (CNO, 2011). Even though the Navy uses these somewhat detailed hourly breakdowns to determine manning levels, a fundamental concern is whether the Navy standard workweek is actually being followed by operational units and if sailors are able to obtain the Navy-directed eight hours of sleep per night. This study aims to contribute to the body of work concerning the NSWW and identify additional shortfalls.

M.   IMPROVED PERFORMANCE RESEARCH INTEGRATION TOOL

The Human Research and Engineering Directorate of the U.S. Army Research Laboratory (ARL) developed IMPRINT to bolster efforts at Manpower and Personnel Integration (MANPRINT) and Human Systems Integration (HSI) organizations (Alion Science and Technology, 2014; ARLHSRED, 2010). IMPRINT takes into account task analysis, workload modeling, performance shaping, degradation functions and stressors, and embedded personnel characteristic data (Alion Science and Technology, 2014; U.S. Army Research Laboratory, Human Research & Engineering Directorate [ARLHSRED], 2010). IMPRINT Pro Version 4.1 is available to and capable of analyzing system and human performance problems for the Army, Navy, Air Force, and Marine Corps.

Only one prior study, conducted by Hollins and Leszczynski (2014) at the Naval Postgraduate School for their master's thesis, has applied IMPRINT Pro to a force level unit of the U.S. Navy. Their study took advantage of detailed work, sleep, and activity data collected by the CNA on personnel aboard the USS *Freedom* (Littoral Combat Ship [LCS]-2) during an underway period. Then, using the Forces module, they examined three different manning levels in order to compare the effects of different manning levels on mission accomplishment. Their study did not, however, take fatigue into account when analyzing crew personnel performance. Furthermore, they did not take full advantage of the stochastic modeling features of IMPRINT Pro (Hollins & Leszczynski, 2014).

1.   Capabilities

IMPRINT Pro is a dynamic, semicustomizable, stochastic, discrete-event modeling tool (ARLHSRED, 2010). It can be used to evaluate the interaction of soldier and system performance throughout the lifetime of a system to include concept, design, field testing, and system upgrades (ARLHSRED, 2010). Specifically, IMPRINT Pro can be utilized to establish realistic system requirements, identify human-driven constraints on system design, evaluate the capability of available manpower to efficiently operate and maintain a system under external stressors, target soldier performance concerns in system acquisition, and estimate human-centered requirements early in the acquisition process (ARLHSRED, 2010). Additionally, a plethora of optional, yet extremely useful, "plug-ins" exist that allow a user to introduce additional capabilities into IMPRINT Pro (Alion Science and Technology Corporation, 2014; ARLHSRED, 2010).

2.   Design

As described by Alion Science and Technology Corporation (2014), Micro Saint Sharp, an embedded, discrete-event, task network modeling language, is the apparatus that drives the operation of IMPRINT Pro. The software utilizes four modules to build and/or parameterize networks that model the flow, and performance time and accuracy of operational missions and maintenance. The four modules are the Warfighters module, the Operations module, the Maintenance module, and the Forces module (recently added to IMPRINT). The Warfighters module provides an analyst with a tool to estimate the type of individuals that will be available to operate and maintain a system. The Operations module can be utilized to estimate the effect of operator performance on the performance of a system. Potential performance measurements include time, accuracy, and/or mental workload effects. The Maintenance module allows an analyst to estimate the maintenance man-hours necessary for attaining an acceptable level of system performance and availability. The Forces module, the

most useful for analyzing Navy manpower problems, can be utilized to analyze manpower requirements based upon planned activities and unplanned events (such as casualties or emergency situations) performed by a large group, such as a department on a ship (Alion Science and Technology Corporation, 2014).

3. Forces Module

The Forces module is the most applicable for analyzing an operational Navy unit at sea and, therefore, will be described in greater detail. Similar to the Maintenance module, the Forces module operates using a stochastic model that relies on user inputs. This module can provide four main insights into an operational unit: the elapsed time for planned and unplanned activities, the cumulative amount of time an activity was performed over the course of the entire model run, the status of an unplanned activity during the model run, and the number of unplanned activities that failed due to leader, subleader, and member requirements not being met (Alion Science and Technology Corporation, 2014). Force analysis data consists of:

- **Force Units:** A group of individuals that perform activities according to a schedule.

- **Schedule:** Pre-defined sequence of activities, planned and unplanned, over a specific time frame.

- **Planned Activity:** A routine task such as eating, sleeping and maintenance.

- **Unplanned Activity:** An activity that interrupts a normal schedule such as an emergency or casualty type situation (e.g., fire and flooding).

- **Activities Priority List:** Used to set task priority within a schedule for when any two activities compete for identical resources.

- **Jobs:** Individuals that are distinguished by the types of functions they can perform. A job is defined by a name, specialty, rank, and role, e.g., "Reactor Operator."

- **Job Role:** The method by which a job (individual) contributes to a force unit. A job and a job role may be identical; however, they may differ when a job is capable of fulfilling more than one role in a force unit. A job may only fulfill one role at a time.

- **Assets:** The means for delivering needed equipment or features to an unplanned activity.
- **Asset Features:** The equipment that is brought by or the features of an asset that determine an asset's usefulness for combating the unplanned activity. (Alion Science and Technology, 2013)

4.   Limitations

IMPRINT Pro has several limitations. Most significantly, it does not yet possess the capability of integrating Design of Experiments (DOE) for creating robust, space-filling designs that allow for regression analysis. Thus, although IMPRINT Pro is a stochastic modeling tool, it is still limited in its ability to simulate and analyze the effects of varying multiple variables across experiments. Second, the general architecture of IMPRINT Pro limits the user's ability to customize simulations and analyses without significant recoding of the IMPRINT baseline code. Unfortunately, this customized approach requires expert-level coding ability in Micro Saint Sharp. Third, IMPRINT Pro's modular design, although convenient for inexperienced modelers, prevents more advanced modelers from being able to combine features from different modules. For example, when using the SAFTE-FAST plug-in with the Forces module, fatigue is used only as a means of selecting the personnel that respond to a particular unplanned activity. Fatigue does not affect the actual performance of personnel responding to the unplanned activity. Finally, IMPRINT Pro does not allow the user to input the number of simulation runs and does not automatically vary the random seed. The user is forced to manually run multiple scenarios and vary the random seed. Running a large number of simulations is nearly impossible due to the sheer man-hours required to do so. Ultimately, this requirement limits IMPRINT Pro's capability in creating space-filling data sets that adequately represent the entire sample space. Unfortunately, these limitations allow for important portions of the sample space to go unexplored by the analyst, reducing IMPRINT Pro's analytical power.

N. SUMMARY

This thesis builds upon past studies by monitoring the sleep of personnel on an aircraft carrier during normal steaming operations. This thesis provides for a better comparison against the Navy standard workweek and yield additional insights into sleep management during normal steaming and flight operations schedules. By collecting actigraphy data, this thesis avoids the pitfalls of some earlier studies that collected only self-reported sleep data. Also, for the first time, this thesis uses SAFTE-FAST to study the fatigue levels and work schedules of an operational unit at sea.

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III. METHODOLOGY

A. OVERVIEW

The main objective of this thesis is to evaluate the sleep of sailors on board the USS *Nimitz* (Carrier Vertical Nuclear [CVN]-68) during normal steaming operations, as part of their 2013 Deployment to the Fifth Fleet AOR. This thesis analyzes two weeks of sleep data collected using continuous measures of actigraphy and self-reported sleep. Sailors completed several different surveys and questionnaires as part of the data collection process. The analysis includes a comparison of actigraphy-monitored sleep and self-reported sleep, as well as a comparison of both forms of sleep data to the NSWW. A comparison of actigraphy-monitored sleep to actigraphy-monitored rest is included as part of the NSWW analysis. Finally, the predicted effectiveness of participants is analyzed using FAST software.

B. PARTICIPANTS

Participants included volunteers from various departments and watch stations on board the USS *Nimitz*. Efforts were made to include sailors and officers standing various watch rotations and performing different duties throughout the ship. All participants signed a consent form, minimum risk consent form, and a privacy act statement prior to data collection. For this analysis, a total of 32 participants were used. Of these participants, 25 were male and 5 were female. The average age of all participants was 27.28 years and ranged from 19 to 35 years. They represented three main departments (groups) of the ship's force, and possessed various educational backgrounds and military experience.

Originally, 35 enlisted personnel and officers on board the USS *Nimitz* volunteered to participate in this study. For the actigraphy analysis portion of the study, however, three of the crewmembers were omitted due to incomplete data sets. Thus, only 32 participants were used for the actigraphy sleep analysis. For the NSWW and comparison of self-reported sleep to actigraphy-monitored sleep

analyses, nine participants were omitted because of either incomplete actigraphy data and/or self-reported sleep data. Thus, only 26 participants were examined for these analyses.

C. APPARATUS

The apparatus utilized for collecting and downloading actigraphy data included the Philips Respironics Actiwatch Spectrum and the Philips Respironics Actireader. The Respironics Actiware 5 software was used for conducting initial data scrubbing and cleaning, and analysis. Sleep and activity logs were used to collect data on the daily activities of each of the participants. Additionally, data was collected through the use of several questionnaires and sleep analysis surveys.

1. Actigraphy

This section describes the apparatuses used for collecting, downloading, and initially cleaning and analyzing the actigraphic data. The sleep and activity logs and the sleep analysis surveys used in this study are also described in this section.

a. *Philips Respironics Actiwatch Spectrum*

Actigraphy was originally developed as a means for empirically measuring and quantifying sleep prior to the advent of polysomnographic techniques. Polysomnography, however, is designed to study human sleep in laboratory settings, not on deployed naval warfighting vessels. Thus, actigraphy provides the only robust means for quantifying the sleep of members of the U.S. military in operational settings. Actigraphs are devices similar to wrist watches. One of the more robust and cost-effective actigraphs currently available is the Philips Respironics Actiwatch Spectrum (see Figure 9) manufactured by Philips Respironics, Inc. Through the use of an accelerometer, the device is able to monitor and store counts of slight body movements, which is then used to determine an individual's sleep periods. Sleep periods are determined through

the use of algorithms built into the software and/or analysis of the graphically displayed actigraphy data by an experienced and well-informed analyst. Although not used in this study, Actiwatch Spectrums also have the ability to monitor and record ambient light through a built-in ambient light sensor (Philips Respironics, 2009.

Figure 9.   Philips Respironics Actiwatch Spectrum (from Philips Respironics, 2009, p. 2).

The memory of the Actiwatch Spectrums are cleared, checked for battery life, reset and reconfigured prior to each use. After the data are collected and stored in the Actiwatch Spectrums, the data are then downloaded to a personal computer using the Respironics Actiware 5 software package. A docking station, known as an Actireader (see Figure 10), uses infrared to communicate with the Actiwatch Spectrums and is connected to a personal computer through a universal serial bus (USB) cable. The Actireader provides the hardware interface for configuring the Actiwatch Spectrums prior to data collection and for downloading the actigraphy data following data collection (Philips Respironics, 2009.

Figure 10.   Philips Respironics Actireader (from Philips Respironics, 2009, p. 2).

2.   Respironics Actiware 5

The software used to configure the Actiwatch Spectrums, download the actigraphy data files, and edit actigraphy data files is called Respironcs Actiware 5 (see Figure 11), developed by Philips Respironics, Inc. The all-in-one nature of this software provides an efficient means for downloading and editing the actigraphy data. Previous actigraphy software required multiple steps for downloading and converting actigraphy data files into a readily usable format.

The Respironics Actiware 5 software program provides a graphical user interface (GUI) for editing and conducting surface-level analysis of actigraphy data, as shown in Figure 11. The software allows the user to create databases for different studies or multiple databases for the same study, if necessary. Within a database, multiple actigraphy data files can be stored. An actigraphy data file is created for each participant and is linked to the sleep watch from which the actigraphy data originated. From the Actiware software, multiple summary statistics for sleep, rest, and wake periods can be exported as a comma separated values (CSV) file, which can then be analyzed further in Excel or reformatted, if necessary, and read into other statistical analysis software.
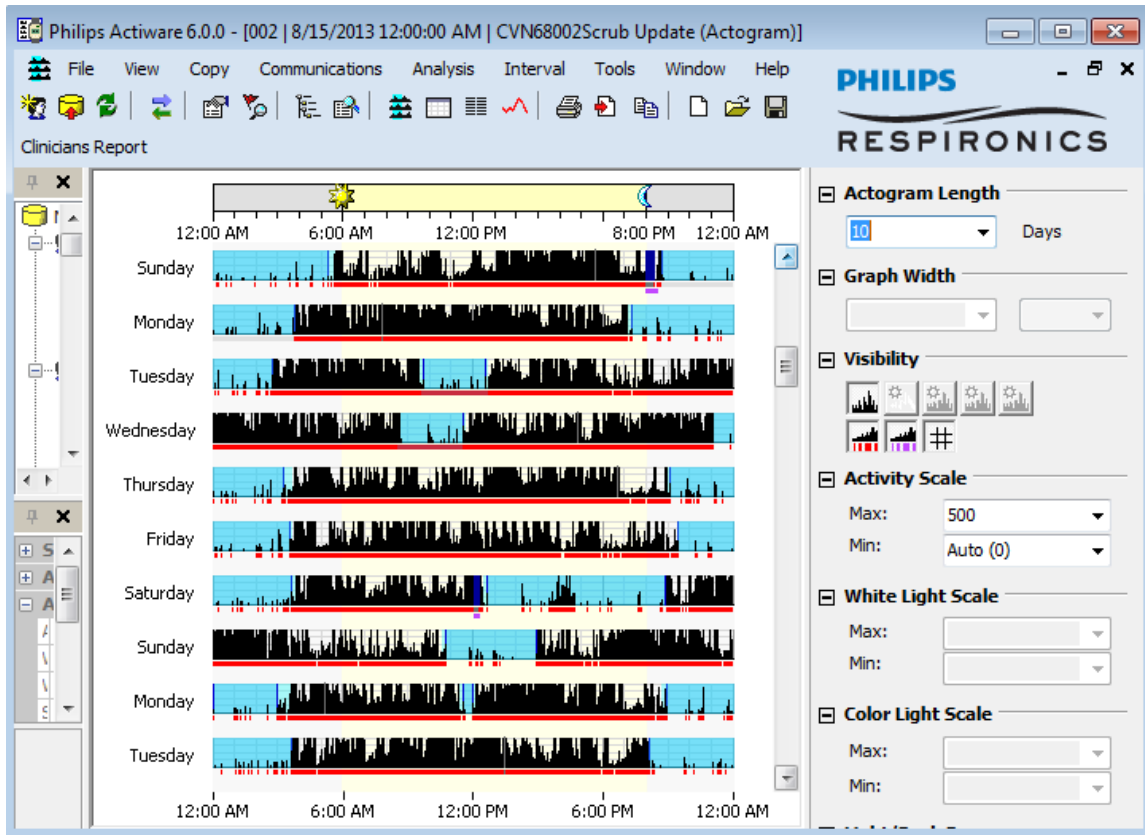
Figure 11.   Screen shot of a participant's actigraphy data, as shown in
Respironics Actiware 5 software version 6.0.0 (after Philips
Respironics, 2013).

As shown in Figure 11, each row of the actigraphy data represents 24 hours of data collected from 0000 to 2400. The time periods highlighted in the darker blue represent sleep episodes, while the lighter color blue, which frequently bookends the sleep episodes, represents rest periods. The rest periods represent the total time that the participant spent in bed, which includes the sleep episode as well. The darkest color blue represents off-wrist time. During these periods, no actigraphy data are available.

Within the software, there are a multitude of options available for editing the data. Algorithms for determining sleep, rest, and wake periods are built into the software and can be activated for assisting in the editing of the actigraphy data. The option can be selected or deselected on a participant-by-participant basis. The software will automatically determine the time periods in which a

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participant most likely removed the Actiwatch (known as off-wrist time). Once again, this option can be selected or deselected on a participant-by-participant basis, as determined by the analyst. Additionally, the user can manually enter rest, sleep, wake, and off-wrist periods, as necessary. There are additional options for entering forced-wake and forced-sleep periods that become necessary under various circumstances, most notably prior to exporting the actigraphy data to SAFTE-FAST.

The software also allows for varying degrees of granularity when editing the actigraphy data. For example, in order to obtain an overall understanding of a participant's sleep over the course of the entire study, a user may choose to view multiple days simultaneously (the software allows up to 21 days to be viewed at once). At some other point in the analysis and editing process, however, it may become necessary to only see one day or less at a time. The software is flexible enough to allow for robust editing of actigraphy data files. Furthermore, the editing capability is absolutely crucial in accurately determining a person's sleep and wake periods.

3.   Sleep and Activity Logs

At the start of the time periods in which the participants were to take part in the study, each individual was issued a sleep and activity log (see Figure 12). Each log was labeled with the participant's identification number. The activities that a participant can log were based on those outlined in the NSWW and participants also logged when they removed the Actiwatch. The activities outlined in the NSWW are sleep, personal time, free time, maintenance and work, training, watch, and service diversion (including meetings). Recording activities in this way allowed for a direct comparison of a participant's daily activities to the NSWW. The logs provided the capability for cross-referencing actigraphy data with self-reported activities during data cleaning. Furthermore, the logs provided a key tool for gaining a better understanding of a participant's daily routine, eating habits, sleep patterns, watch rotations, and additional duties. This

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information contributed significantly to determining the correct periods in which a participant was actually sleeping, resting, or awake, and ultimately provided for more accurate sleep and rest data. The logs also provided the opportunity to compare self-reported sleep and actigraphic sleep.

USS Nimitz
Watchstanding Study

Daily Activity / Sleep Logs: Week 1

Date _____

On-Duty Activity		Off-Duty Activity	
M	Maintenance/Work	PT	Personal Time*
T	Training	E	Eating / Messing
W	Watch	F	Sunday/Holiday/Freetime
D	Meetings	S	Sleeping
SD	Service Diversion**	R	Removed WAM

* Personal Time Consists of: Time spent working out, grooming, cleaning personal space, etc.

** Service diversion consists of actions required of military personnel by regulations or the nature of shipboard/staff routine. Service diversion includes, but is not limited to, the following types of activities:
(1) Quarters, inspections, and sick call.
(2) Other administrative requirements including: Commanding Officers Non-Judicial Punishment (NJP), participation on boards and committees, interviews, and non-training-related assemblies.
(3) Flight and hangar-deck integrity watches.

Hours of Daylight Exposure: _____

Additional Notes:

Figure 12.   Sleep and Activity Log provided to participants on the USS *Nimitz*.

The log divided a 24-hour period, in this case 0000 to 2400, into 15-minute blocks. Throughout the period in which an individual participated in the study (i.e., wore an Actiwatch), they recorded their daily activities, to include sleep to

the nearest 15 minutes. The day was separated into on-duty or available time and off-duty or non-available time. Available time and non-available time are further broken down into subcategories. Available time was split up into these categories: watch, maintenance and work, training, meetings, and service diversion. Non-Available time was split into these categories: sleep, messing, personal time, and free time. Participants were instructed to annotate any off-wrist time as well.

4. Questionnaires

Questionnaires were used to gather basic information about each of the participants as well as information specifically focused on the period of time in which the study was conducted. Sleep analysis surveys were used to collect additional data about participant sleep.

a. Demographic Questionnaire

The purpose of the demographic questionnaire was to gather basic information such as gender, age, rank, rate, department, years of service, number of times deployed, watch section, watch rotation, etc. Participants filled out a hard copy version with either pencil or pen. Appendix A contains a copy of the demographic questionnaire.

b. End-of-Study Questionnaire

The purpose of the end-of-study questionnaire was to gather additional information about each participant that was specifically focused on the period of time in which the study was conducted. First, the questionnaire was used to determine any changes in a participant's watch rotation and/or watch section and to determine if an individual had any collateral duties during the period in which the study was conducted. Second, the questionnaire sought to obtain each participant's opinion in regards to the amount of sleep he or she received and that others received during the study period. Third, it asked several open-ended questions regarding watchstanding schedules. Finally, the questionnaire

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gathered information about participants' berthing location, rack orientation, and environmental factors affecting sleep. Participants filled out a hard copy version with either pencil or pen. See Appendix B for a copy of the end-of-study questionnaire.

5. Sleep Analysis Surveys

The sleep analysis surveys were distributed at the same time as the demographic questionnaires. The overall purpose of issuing these surveys was to gain additional insight into the quality of each participant's sleep, the sleepiness level of each participant, and determine participants' sleep preferences.

a. *Pittsburgh Sleep Quality Index*

The purpose of the PSQI was to determine the quality of each participant's sleep. It is a self-administered questionnaire that assesses an individual's sleep quality and disturbances. Participants filled out a hard copy version with pencil or pen. Appendix C contains a copy of the PSQI that participants filled out for this study.

b. *Epworth Sleepiness Scale*

The purpose of the ESS was to determine the daytime sleepiness and any potential sleep disorders of participants in the study. The ESS is a self-administered instrument designed to assess the level of an individual's daytime sleepiness. Participants filled out a hard copy version with pencil or pen. Appendix D contains a copy of the ESS that participants filled out for this study.

c. *Composite Scale of Morningness*

The purpose of the CSM was to determine if a participant is an owl (night person), lark (morning person), or robin (neither). The CSM is a self-administered instrument that is used to measure an individual's behavioral temporal

preference. Participants filled out a hard copy version with pencil or pen. Appendix E contains a copy of the CSM that participants filled out for this study.

D. IMPLEMENTATION AND DATA COLLECTION

This study presented several unique challenges not yet faced by previous sleep theses at NPS. First, all sleep-monitoring equipment, questionnaires, and surveys needed to be mailed to the USS *Nimitz* while the ship was already on deployment to the Fifth Fleet AOR. Thus, the sleep watches were set to Zulu time, which presented challenges during data cleaning and analysis due to various time offsets as the ship changed geographic time zones throughout the study. Additionally, all sleep-monitoring equipment was activated prior to being mailed to the ship and the initiation of the official study; thus, there are a significant number of days with no sleep or activity data. Eliminating this unnecessary data required additional data cleaning. Second, in order to complete the study, the USS *Nimitz*'s Senior Medical Officer, Commander (CDR) John Moore, was relied upon to conduct all briefs and issue all sleep-monitoring equipment, surveys, and questionnaires. He was an essential member of the research team for this thesis. Final data collection occurred over a two-day period during the ship's port call in Pearl Harbor, Hawaii. During this time period, various watchbills, unclassified operational schedules and deck logs, and, when possible, missing surveys, questionnaires, and sleep-monitoring equipment were collected. Finally, the unique nature of this study potentially contributed to a reduced number of participants and less complete data than otherwise may have been obtained.

1. Actigraphy

This section describes the method by which the Actiwatches were configured, how the Actiware 5 software was utilized, the periods of time in which data collection took place, and how many participants' data were used for the analysis of actigraphic sleep data.

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a.   *Philips Respironics Actiwatch Spectrum*

Prior to mailing the Actiwatches to the USS *Nimitz*, each was configured and initialized for data collection. Thus, the Senior Medical Officer issued the Actiwatches to participants without any additional manipulation. The serial number of the Actiwatch and an identification number (ID) was linked to each participant in order to ensure actigraphy and activity log data were matched to the correct participant. Each Actiwatch was labeled with a corresponding identification number to provide for easier cross-referencing of Actiwatch to participant during data collection and analysis. Actiwatches and data collection packets of sleep and activity logs were assigned to participants during three overlapping time periods, with participants taking part in only one of the time periods. The time periods in which participants wore Actiwatches and completed sleep and activity logs were: August 26, 2013 to September 11, 2013, September 3, 2013 to September 17, 2013, and September 11, 2013 to September 24, 2013.

Although the time periods varied in which data was collected, the USS *Nimitz*'s operations were consistent throughout the entire time period in which the study was conducted. This schedule was verified through interviews with members of the crew, deck logs, and the daily operational schedule of the ship, also known as the daily "Green Sheet." This provided for consistency in the operational environment between the time periods, thus preventing significant differences in the daily requirements between the groups as a result of the ship's mission. Any difference between groups was not a result of differences in the ship's operational schedule, but rather a result of the unique job, responsibilities, and/or watch of the participants. Upon completion of each of the time periods, the Actiwatches and sleep logs were collected from the participants and stored on board the ship. The Actiwatches and completed sleep and activity logs were collected from the ship between December 3, 2013 and December 5, 2013. The data were then downloaded to a personal computer using Respironics Actiware 5 software and the Actiwatch Sprectrum Actireader.

b. Respironics Actiware 5

Prior to mailing the Actiwatches to the USS *Nimitz*, a database was created linking each Actiwatch by serial number to an entry in the database (labeled by participant ID number). Thus, when the actigraphy data were downloaded, the software automatically matched each Actiwatch to the appropriate entry in the database.

During the experiment, 35 participants were issued Actiwatches. Due to unexpected equipment failures, however, only 32 of the 35 participants were used in the analysis of actigraphy sleep as a result of significant amounts of missing actigraphy data because of participants removing their Actiwatches and other problems. Of these 32 participants, 11 were commissioned officers, 14 were from the Reactor Department, and 7 were from the Deck Department. Officers were not included in the Reactor Department and Deck Department numbers, but rather only in the commissioned officers group. This grouping was chosen due to the uniqueness of officer schedules and responsibilities, compared to that of enlisted personnel.

2. Sleep and Activity Logs

Sleep and activity logs were issued to each participant at the beginning of the period in which they participated in the study. Each participant was provided basic instructions on how to fill out the log by a knowledgeable individual within the USS *Nimitz*'s Medical Department. In addition, a detailed example on how to properly fill out the sleep and activity log, as displayed in Figure 13, was included in the beginning of every log.

This example shows an activity / sleep log for a crew member. The detailed descriptions of what the person did throughout the day is shown in the red boxes to show why the person filled out the log in this manner.

Figure 13.   Detailed example that was provided to each participant on how to properly fill out the sleep and activity logs.

Due to several nearly incomplete sleep and activity logs, and other participants failing to return their logs, only 26 of the 35 participants were used in the analysis of self-reported sleep and the NSWW. Of the 26 participants, 10 were commissioned officers, 13 were from the Reactor Department, and 3 were from the Deck Department.

3.   Questionnaires

A demographic questionnaire and an end-of-study questionnaire were completed by each participant at the beginning and at the end of the study period in which he or she participated, respectively.

a.   *Demographic Questionnaire*

Participants completed the demographic questionnaires at the beginning of their participation period; however, since all participants did not return Actiwatches and/or sleep and activity logs at the end of the study period, not all demographic questionnaires were retained for analysis. Demographic surveys were retained for the 32 participants used in the actigraphy analysis and for the 26 participants used in the self-reported sleep and NSWW analysis.

b.   *End-of-Study Questionnaire*

Participants completed the end-of-study questionnaires upon conclusion of their participation in the study; however, since all participants did not return Actiwatches and/or sleep and activity logs at the end of the study period, not all end-of-study questionnaires were retained for analysis. Additionally, some individuals did not fill out exit surveys and/or some exit surveys were lost prior to final collection of materials in early December. As a result, 26 end-of-study questionnaires were used for the actigraphy and self-reported sleep analyses.

4.   Sleep Analysis Surveys

Participants completed all three sleep analysis surveys at the beginning of their participation period when they filled out the demographic questionnaire; however, since all participants did not return Actiwatches and/or sleep and activity logs at the end of the study period, not all sleep analysis surveys were retained for analysis. Other contributing factors for not retaining some surveys included not answering a significant number of questions on a survey or answering a significant number of questions inappropriately. As a result, 32 of

the 35 surveys were retained and utilized for analysis. For the comparison of actigraphy and self-reported sleep, only 26 participants' sleep analysis surveys were used.

5. SAFTE-FAST

This study, for the first time, used SAFTE-FAST to analyze the predicted effectiveness of U.S. Navy personnel on an operational unit at sea. SAFTE-FAST, as described in Chapter I, is a robust and user-friendly tool used by schedulers and operational planners for determining optimal sleep and work schedules to mitigate the effects of fatigue. Although SAFTE-FAST has only been used in the aviation (civilian and military) and rail industries to this point, this thesis took advantage of SAFTE-FAST's batch processing and unique algorithms in order to analyze the predicted effectiveness of watchstanders on the USS *Nimitz*. The detailed summary files offered by SAFTE-FAST allowed for analyzing not only average watchstander effectiveness during watch, but how operator effectiveness changed over time throughout a watch period. Furthermore, SAFTE-FAST's built-in graphical features and fatigue analysis tools were used to gain better insight into personnel work, sleep, fatigue, and performance patterns. Thus, by simultaneously analyzing the ship's operational schedule and available watchbills, SAFTE-FAST allowed for the detection of critical times when personnel fatigue detrimentally impacted effectiveness and had the potential to negatively impact the ship's operations.

E. DATA ENTRY AND FORMATTING

Due to the large amount of handwritten data collected in this study, data entry proved to be time consuming and challenging. To guard against data entry mistakes, however, a third party was used to verify that all data were entered correctly. Additionally, automatic formatting and data processing techniques via Visual Basic for Applications (VBA) were utilized to reduce data entry errors and provide for easier subsequent analysis.

1. Sleep and Activity Logs

Initially, all participants' handwritten sleep and activity logs were entered into a Microsoft Excel 2010 file. The template used for the electronic version of the logs is shown in Figure 14. Due to either a significant amount of missing data or some participants not returning the log, only 26 participants' hand-recorded logs were transferred to the Excel file.

Figure 14. Template used for electronically recording each participant's handwritten sleep and activity log data.

A single Excel workbook contained all of the activity and sleep logs, with a separate tab for each participant. The handwritten logs were transferred to the Excel file by typing in the appropriate code for each activity, as shown in Figure 15. VBA code was then used to automatically color the cells, based on the entry in each cell, which reduced additional data entry time. Coloring the cells more

clearly delineated the activities and allowed for easier detection of patterns in the data. The transferred data were verified against the handwritten logs by a third party to ensure correctness of the initial data entry.

Legend				
On Duty		**Off Duty**		
Activity	Code	Activity	Code	
Maintenance	M	Sleeping	S	
Training	T	Messing	E	
Meetings	D	Personal Time	P	
Watch	W	Removed WAM	R	
Service Diversion	SD	Free Time	F	
Unknown	U			

Figure 15.   Legend showing the appropriate codes and automatic coloring for each activity.

Of the 26 sleep and activity logs that were used in the study, additional data cleaning was still required. Because each individual's daily routine, jobs, watch rotation, and sleep and wake patterns were unique, special care was taken when editing the self-reported sleep and activity data. Thus, by using patterns in each participant's daily routine and cross-referencing actigraphy data, watchbills, and the ship's operational schedule with a participant's sleep and activity logs, time periods in which an individual did not log activities or sleep were edited to correctly reflect an individual's activities. This process was also accomplished for time periods in which the participant logged the Actiwatch as removed, but based upon other data, a participant's activities could be deduced. These methods of editing were only used for periods of time in which it was obvious, based upon a cross-reference analysis of the ship's operational schedule, watchbills and patterns in a participant's actigraphy data and daily routine, that a participant was engaged in a particular activity or sleeping. Any time that could not be accounted for—even after following this method—was designated as "unknown." By completing such editing, additional data could be retained for analysis and the most accurate data could be used.

2. Actigraphy

Of the actigraphy data that were retained, additional data cleaning was still required. Because each individual participant displayed different actigraphy data while sleeping and while awake, special care was taken when editing the actigraphy data. Some participants were more active sleepers, while others showed little movement while asleep. Furthermore, each participant displayed a unique daily routine that could include watch, naps, free time, etc. Thus, the actigraphy data, patterns in the actigraphy data, each participant's sleep and activity log, patterns in each participant's sleep and activity log, and the ship's operational schedule were all used to edit the sleep, rest, and wake periods of each participant.

After data cleaning, an output .csv file was generated. The Actiware 5 software allows the user a plethora of choices in regards to the amount and type of data that are output. This data included the start and end dates and times for all rest and sleep intervals for each participant and the duration of each rest and sleep interval. Following some additional formatting, this tabular data set was saved as a .csv file and then imported into R Version 3.1.0 for subsequent analysis.

3. Questionnaires

This section describes the methods used for data entry and formatting for the questionnaire and sleep analysis survey data.

a. Demographic Questionnaires

Because the demographic questionnaires were filled out by hand by each of the participants, each had to be transferred into Microsoft Excel 2010 to allow for analysis. A single Excel worksheet was used, with each row corresponding to a participant and each column to a question or sub-question in the questionnaire. Although each participant answered some questions slightly differently, the reported data were re-coded during data transfer in order to standardize the

entries in the Excel file. A portion of the missing demographic data was accounted for by using the end-of-study questionnaires, the ship's operational schedule, watchbills, and sleep and activity logs.

b. End-of-Study Questionnaires

End-of-study questionnaires were transferred into Microsoft Excel 2010 for analysis. A single Excel worksheet was used, with each row corresponding to an individual and each column to a questions or sub-question in the survey. Even though each participant answered some questions slightly differently, the reported data were re-coded during data transfer in order to standardize the entries in the Excel file. A portion of the missing exit survey data was accounted for by using the demographic questionnaires, the ship's operational schedule, watchbills, and sleep and activity logs.

4. Sleep Analysis Surveys

Specialized Microsoft Excel 2010 files were created in order to score the PSQI, ESS, and CSM. Due to the surveys being completed with pen or pencil and paper, each participant's results were manually transferred into the appropriate Excel file. Most participants correctly completed the surveys; however, some additional data cleaning was required. A third party verified all data entry for correctness.

a. Pittsburgh Sleep Quality Index

The PSQI survey results were calculated for each participant on a single worksheet within an Excel workbook. Each participant occupied a row and the columns accounted for the different questions in the PSQI. Columns were also made for the final PSQI global score calculation and the sleep quality category, as determined by the PSQI global score. The necessary formulas for calculating the PSQI global score were built into the worksheet. Thus, as each participant's answers were transferred into the Excel document, the score automatically updated. Nearly all participants appropriately answered each question; however,

stochastic mean value data imputation was used for the hours in bed determination for five participants because their sleep and wake times were unable to be accurately determined. With this form of imputation, the missing values were replaced with the sample average that had a normally distributed error, with a variance equal to the sample variance.

Once the PSQI global score and sleep quality category were determined, the two columns containing these results were saved in a new .csv file. Then, following additional formatting, the .csv file was saved and imported into R Version 3.1.0 for subsequent analysis.

b.   Epworth Sleepiness Scale

ESS results were calculated for each participant on a single worksheet within an Excel workbook. Each participant occupied a row and the columns accounted for the different questions in the ESS. Columns were also made for the total score and the sleepiness level, as determined by the total score. All participants appropriately answered each question.

Once the total score and sleepiness level were determined, the two columns containing these results were saved as a new .csv file. Then, following additional formatting, the .csv file was saved and imported into R Version 3.1.0 for subsequent analysis.

c.   Composite Scale of Morningness

CSM results were calculated for each participant on a single worksheet within an Excel workbook. Each participant occupied a row and the columns accounted for the different questions in the CSM. Columns were also made for the total score and the preference category, as determined by the total score. Several participants inappropriately checked multiple answers for several questions. Thus, a decision was made to choose the marked response that had the least effect on the results of the total score (i.e., the response that was closer to the median of the scale for that question).

Once the total score and the preference category were determined for each participant, the two columns containing these results were saved in a new .csv file. Then, following additional formatting, the .csv file was saved and imported into R Version 3.1.0 for subsequent analysis.

5.   Predicted Effectiveness

In order to obtain the predicted effectiveness of participants using SAFTE-FAST, three main files were generated: an explicit sleep file, a schedule file, and a duty file. The explicit Sleep file is an Excel file containing the actigraphic sleep episodes of all participants. To generate the explicit Sleep file, first, the actigraphy data were edited using the Respironics Actiware 5 software, as described in the previous section. Then a .csv file containing the sleep intervals (to include date, time, and duration) for all participants was exported from the Actiware software. The file was opened in Excel in order to conduct initial formatting of the data. Subsequently, the file was imported into R Version 3.1.0, where additional formatting was completed. Finally, a .csv file, properly formatted and ready to be imported into the SAFTE-FAST software, was generated using R.

The schedule file is the file used for preconditioning the sleep for each participant. Specifically, this file is used to establish sleep and effectiveness for the three days prior to the start of the study period. Because work, sleep, and activity patterns are unknown prior to the start of a study period, the *AutoSleep* feature of SAFTE-FAST is used to establish the best estimate of sleep and predicted effectiveness prior to the start of the actual study period. All participants were preconditioned so as not to allow a predicted effectiveness of less than 95% prior to the start of the actual study period. The schedule file was generated using Excel.

The duty file is the one used to determine the period of time in which each participant was on watch. Although any type of activity, such as training or maintenance, can also be entered into the duty file, watch was used in this study

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because it is the time when an individual is expected to be at their peak performance and is the most interesting type of activity to analyze. The duty file was created using Excel.

Once the three necessary files were generated, SAFTE-FAST was used to generate a summary File and a FAST effectiveness graphic for each participant. The summary file, following additional formatting, was exported as a .csv file and read into R Version 3.1.0 for subsequent analysis. The FAST effectiveness graphics were exported as FAST schedule files and used to gain insight into each participant's overall pattern of sleep and activity, and their predicted effectiveness during periods of watch. The FAST graphic provides a useful tool for identifying particular individuals that warrant further investigation and to examine overall trends in each participant's predicted effectiveness.

IV. RESULTS AND DISCUSSION

A. OVERVIEW

This chapter contains the statistical analyses performed on the demographic questionnaires, actigraphy data, self-reported sleep, sleep analysis surveys, and SAFTE-FAST-generated predicted effectiveness data. Section B of this chapter provides results of the statistical analyses of demographic and sleep analysis survey data. Section C contains detailed results of the statistical analyses of the actigraphic sleep data and Section D contains results from an analysis of the NSWW. Section E provides a comparison of the self-reported sleep and actigraphic sleep data, while Section F details the results of the SAFTE-FAST analysis.

B. ANALYSIS OF DEMOGRAPHIC AND SLEEP ANALYSIS SURVEY DATA

The 32 participants represented various departments throughout the ship and had varying levels of military experience and educational backgrounds. The data were examined for potential differences in age, gender, commissioning status (officer or enlisted sailor), department, and watchstation location. Also, potential differences in ESS and CSM results were examined. Of note, although not discussed in detail in this chapter, the PSQI analysis determined that all but one participant experienced poor sleep quality while at sea.

In the subsequent sections, unless otherwise noted, due to ties in the data, normally approximated confidence intervals for the medians of the respective variables and categories of interest, as calculated by Wilcoxon Signed Rank tests (with no continuity correction), are provided in the tables of summary statistics. Furthermore, as a result of ties in the data, the p-values calculated using Wilcoxon Rank Sum Tests (α = 0.05) are normally approximated. For all analyses involving count data, the Pearson's Chi-squared Test was used and verified against the results of the Fisher's Exact Test. When the results were in

close agreement, the p-value calculated using the Pearson's Chi-squared Test was reported; otherwise, the p-value calculated by the Fisher's Exact Test was reported.

In order to examine differences between departments, the participants were separated into the following three groups: Deck Department, Reactor Department, and officers. Furthermore, since each group used a different watch schedule (e.g., 5ON/10OFF Deck Department, 5ON/15OFF Reactor Department, and 4ON/20OFF officers), separating the participants into these groups provides additional insight into the different watch schedules. A 5ON/10OFF watch schedule means that an individual stands five hours of watch and then has 10 hours off watch before going back on watch again. During the 10 hours off, an individual is expected to work, take care of personal issues, eat, and sleep. The other watch rotations follow the same routine, but with different amounts of on-watch and off-watch time.

The analysis considers officers as a separate "department" because officer schedules are traditionally much different from those of enlisted sailors. Although, in this study, officers come from a wide variety of actual departments (Administration, Weapons, Engineering, etc.), they shared similar day-to-day schedules, warranting separating the participants into separate groups.

1.   Age

The summary statistics for participant age are displayed in Table 4. Table 5 presents the two-tailed p-value and the name of the statistical test used for the tests of statistical significance conducted with regard to age for the different variables of interest.

	Mean	Median	Range	Std Dev	Skewness	Kurtosis	Confidence Interval (95%)
All Participants	27.3	27.0	[19, 35]	5.0	−0.08	1.63	[25.5, 29.5]
Male	28.0	27.0	[21, 35]	4.5	−0.30	1.9	[26.5, 30.0]
Female	24.7	22.0	[19, 35]	6.5	0.90	1.9	[20.0, 30.0]
Enlisted	25.1	25.0	[19, 35]	4.6	0.63	2.3	[22.5, 27.0]
Officer	31.6	32.0	[27, 35]	2.5	−0.80	2.7	[29.5, 33.0]
Reactor	26.5	26.5	[21, 35]	4.2	0.50	2.4	[24.0, 29.5]
Deck	22.1	21.0	[19, 31]	4.0	1.80	4.7	[19.5, 26.5]
Belowdecks	25.7	25.5	[20, 35]	4.4	0.50	2.2	[23.5, 27.5]
Topside	29.9	31.5	[19, 35]	5.1	−1.30	3.3	[26.0, 33.0]

Table 4.   Summary statistics of participant age (n=32).

	p-value (2-tailed)	Type of Test	Statistically Significant?
Gender	0.18	Wilcoxon Rank Sum	No
Commissioning Status	0.0004	Wilcoxon Rank Sum	Yes
Department	0.0004	Kruskal-Wallis Rank Sum	Yes
Watchstation Location	0.03	Wilcoxon Rank Sum	Yes

Table 5.   P-value results and the name of the statistical test used for determining statistical significance (α = 0.05) in regards to age for the variables of interest.

The distribution in Figure 16 shows that the seven females are split between the younger and older age groups. Additionally, 22 of the 32 participants reported that they were at least 25 years old. Eighty percent of male and 29% of female participants were identified as being 25 years or older. Of note, the majority of female participants were 24 years or younger, yet there were two female participants 33 years or older as well.
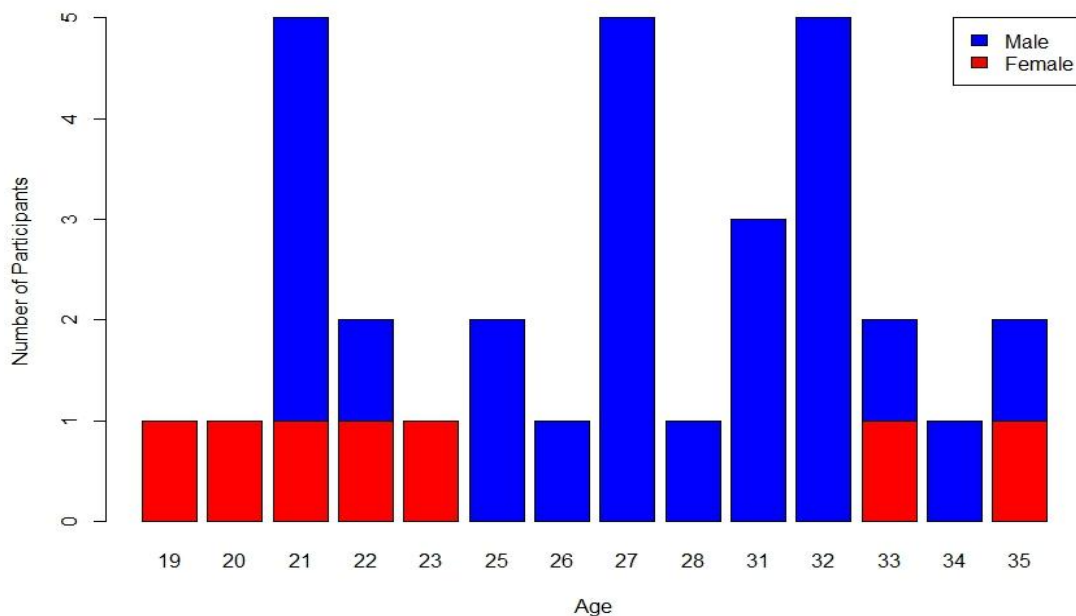
Figure 16.   Histogram of age delineated by gender.

2.   Gender

Seventy-eight percent (25/32) of participants were males; 22% of participants were female. Possible gender differences in questionnaire and survey responses, and actigraphy and self-reported sleep and activity data are described in subsequent sections.

3.   Commissioning Status

As shown in Figure 17, 66% (21/32) and 34% (11/32) of participants were enlisted and officer personnel, respectively. Eighty-six percent of female and 60% of male participants were enlisted, while 14% of female and 40% of male participants were officers.
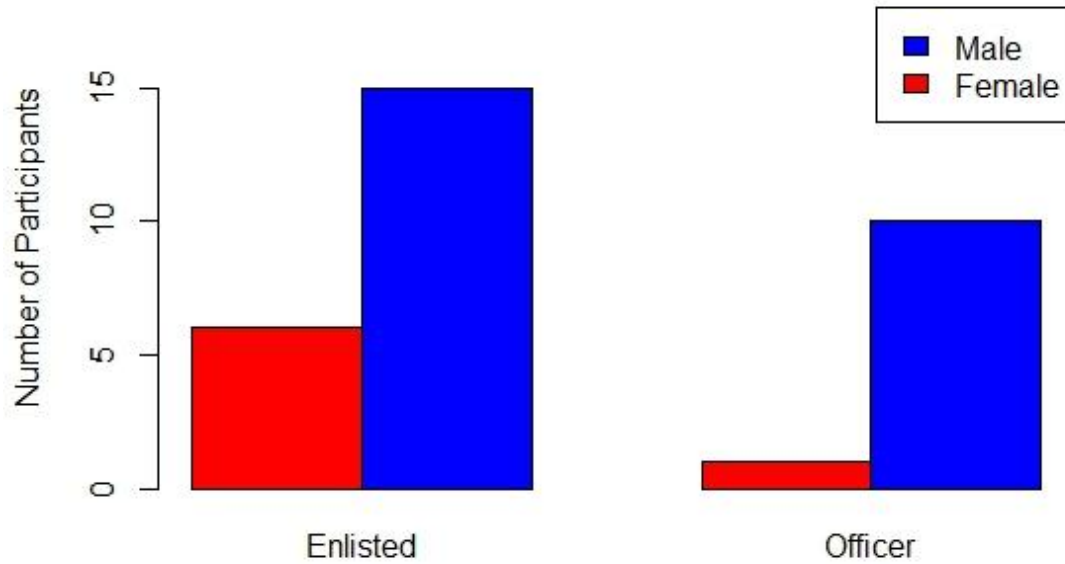
Figure 17.   Bar plot for the number of enlisted and officer participants delineated by gender.

As shown in Figure 18 and Table 4, the range of ages for enlisted participants was greater than the range of ages for officers. As shown in Table 4 and Table 5, officers in this study tended to be older than enlisted participants.
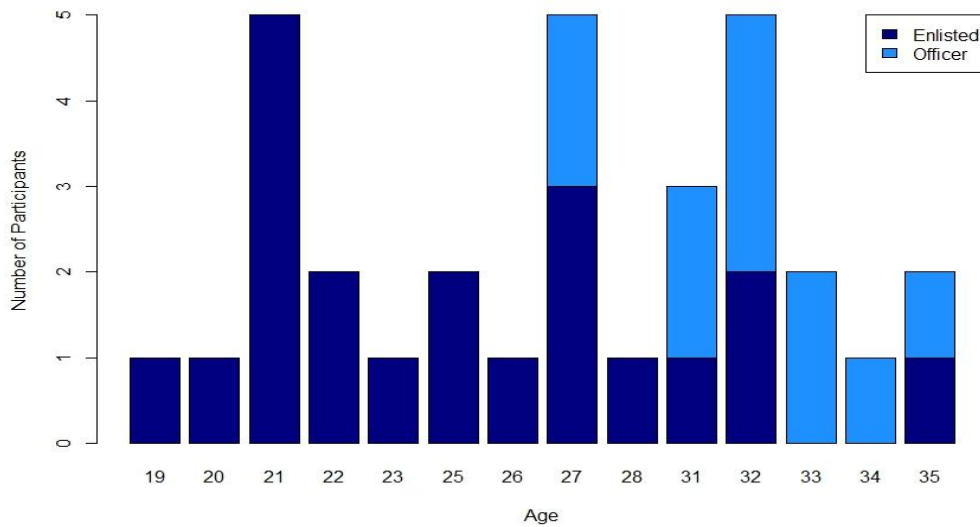
Figure 18.   Histogram of age delineated by commissioning status.

4. Department

The Deck Department was the only predominantly female department (see Figure 19); however, all departments consisted of both males and females. Based on the Fisher's Exact Test for Count Data (α = 0.05), the difference in the proportion of males and females in each department was significant at the p-value = 0.06 level, due to the proportionally higher number of females in the Deck Department.
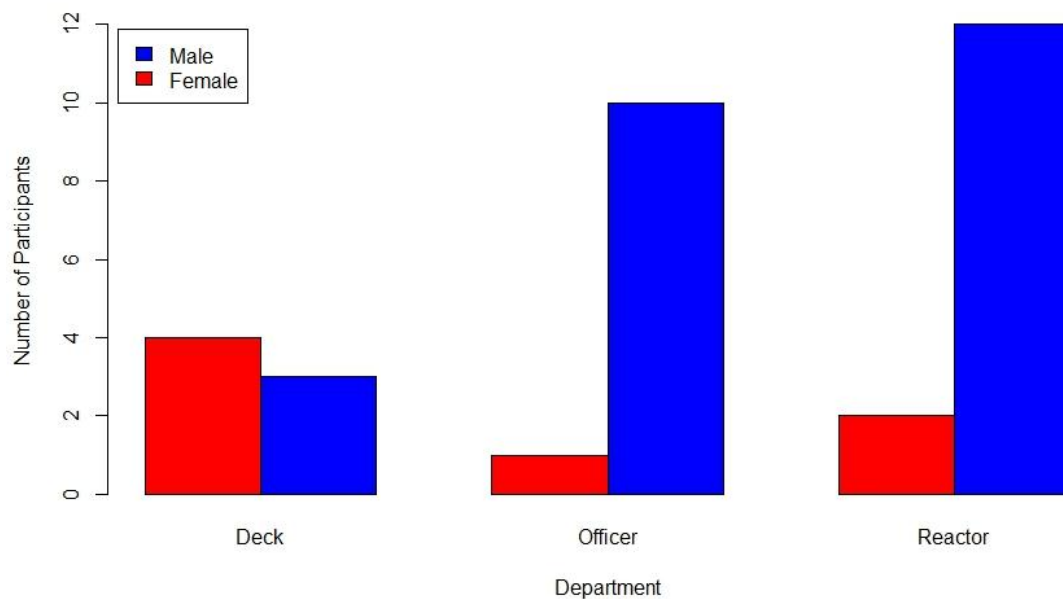
Figure 19. Bar plots of department delineated by gender.

Table 4 displays the summary statistics for age by department.. Figure 20 illustrates that the age ranges of the departments differed. As shown in Table 5, the difference in age between the departments was statistically significant (p-value = 0.0004). Officers tended to be older, while the Deck Department was the youngest group.
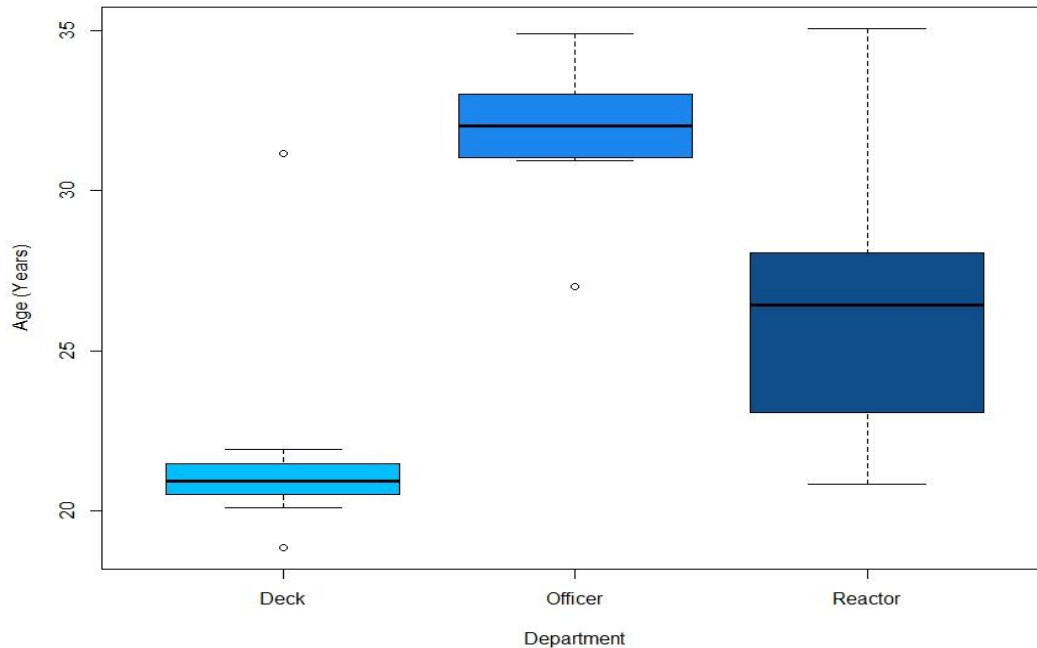
Figure 20.   Boxplot of age by department.

Based on a pairwise Multiple Comparison Wilcoxon Rank Sum Test using the Holm's p-value adjustment procedure (family-wide α = 0.05), a statistically significant difference in age existed between each of the departments. The p-values for each of the pairwise comparisons are displayed in Table 6.

	Deck	Officers
Officers	0.004	-
Reactor	0.020	0.010

Table 6.   Table of pairwise p-values for comparing the age of participants of the three different departments using the Multiple Comparison Wilcoxon Rank Sum Test, using the Holm's procedure for p-value adjustment.

5.   Location of Watchstation

Watchstation location was broken down into two categories, topside and belowdecks, in order to investigate potential differences between participants'

exposure to sunlight while on watch. The topside category includes all watchstanders exposed to sunlight while on watch. Table 4 presents the summary statistics for age by watchstation location. Figure 21 provides additional information about age in regards to watchstation location. As shown in Table 5, there is a statistically significant difference in age between watchstation locations (p-value = 0.03).
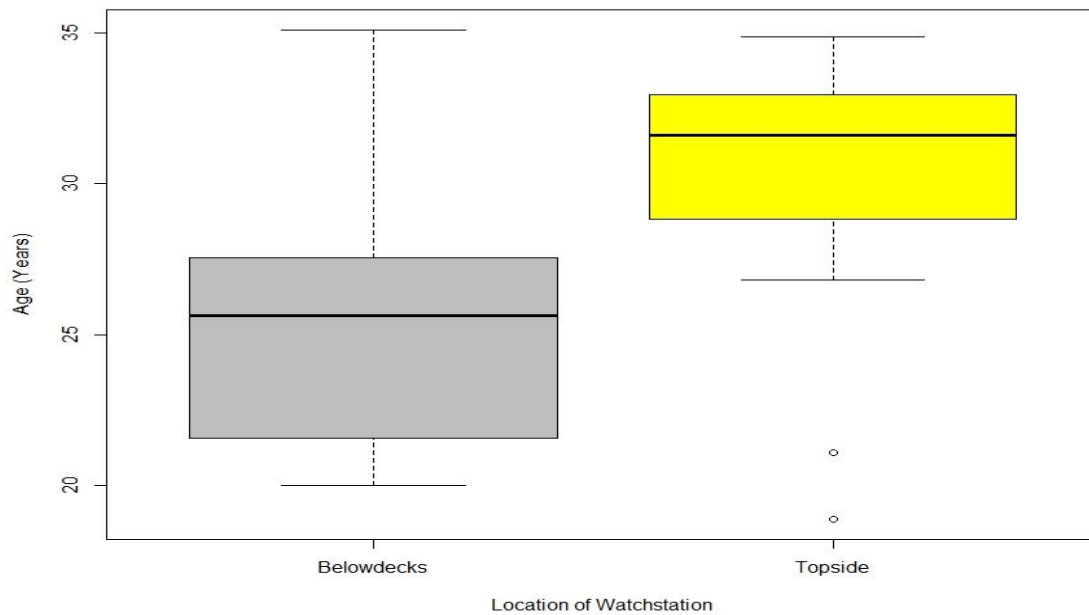
Figure 21.   Boxplot of age delineated by watchstation location.

Figure 22 shows the distribution of watchstanding location by department, with only belowdecks watchstanders in the Reactor Department, since all Reactor Department watchstations are located in the engine room on the lower decks of the ship. Nine of the 11 (82%) officer participants stood watch topside. The Deck Department was nearly evenly split, with three topside and four belowdecks watchstanders. Based on the Pearson's Chi-squared Test with simulated p-value (α = 0.05, replications = 10,000), the difference in the proportion of participants standing watch topside and belowdecks between departments was statistically significant (p-value = 0.0003), indicating that a

greater proportion of officers stood watch topside and a greater proportion of Reactor Department personnel stood watch belowdecks.
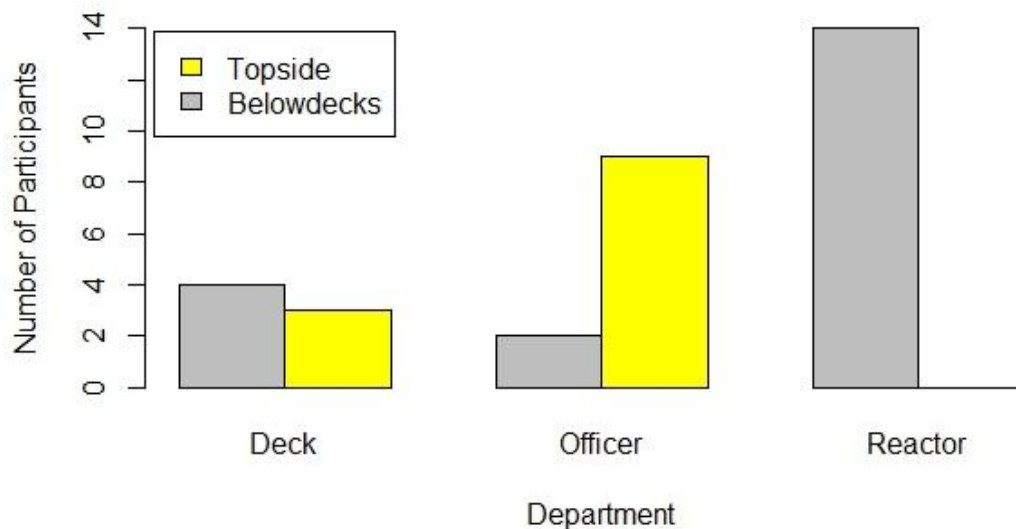
Figure 22.   Bar plot of watchstanding location delineated by department.

6.   Epworth Sleepiness Scale

ESS scores greater than 10 are considered elevated and those less than or equal to 10 are considered to be normal, as described in Chapter II, Section H.2. The overall distribution of ESS scores, as shown in Figure 23, appears to be somewhat normally distributed. The Shapiro-Wilk Test for normality (α = 0.05) suggests that it is reasonable to assume that the ESS scores are normally distributed (p-value = .55); however, normality was not assumed in subsequent analyses. The number of participants with normal and elevated ESS scores was 17 and 15, respectively.
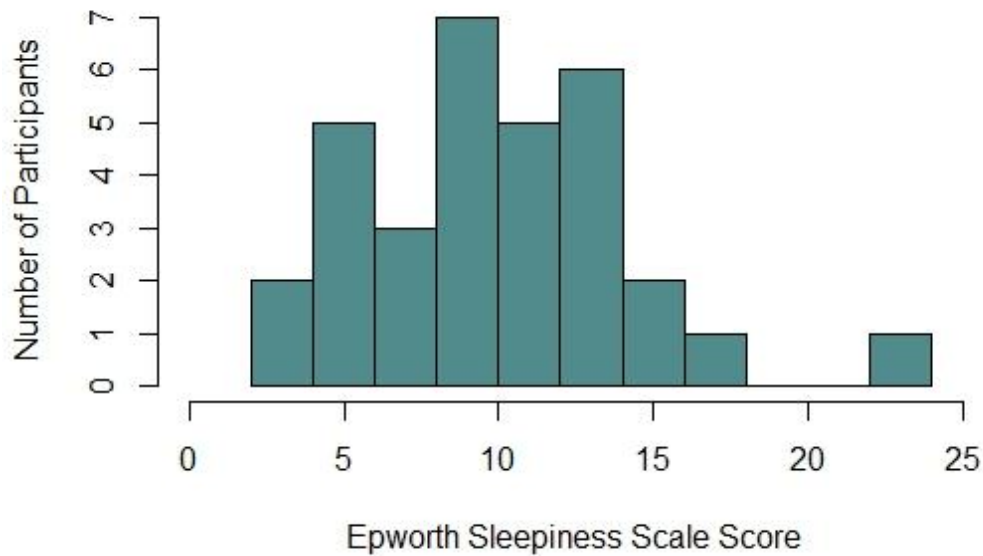
Figure 23.   Distribution of ESS scores for all 32 participants.

In order to gain better insight into any potential differences in ESS scores among the different demographic groups, ESS scores were examined according to age, gender, commissioning status, department, watch location, and CSM-determined chronotype. The summary statistics for ESS scores are displayed in Table 7. Table 8 presents the two-tailed p-value and the name of the statistical test used for each of the tests of statistical significance conducted, with regard to ESS score, for the different variables of interest.

	Mean	Median	Range	Std Dev	Skewness	Kurtosis	Confidence Interval (95%)
All Participants	10.5	10.0	[2, 23]	4.3	0.44	3.6	[9.0, 12.0]
Male	10.4	10.0	[2, 23]	4.4	0.60	4.3	[7.5, 15.0]
Female	10.9	11.0	[5, 17]	4.6	−0.20	1.7	[8.5, 12.0]
Enlisted	11.6	12.0	[5, 23]	4.0	0.80	4.5	[10.0, 13.0]
Officer	8.3	8.3	[2, 16]	4.3	0.40	2.2	[5.0, 11.0]
Reactor	11.6	12.0	[5, 23]	4.2	1.20	4.2	[9.0, 13.5]
Deck	11.6	13.0	[5, 17]	3.9	−0.37	2.4	[7.0, 15.5]
Belowdecks	10.9	11.0	[4, 23]	4.6	0.70	3.7	[8.5, 13.0]
Topside	9.8	10.0	[2, 16]	4.0	0.34	2.4	[7.0, 12.5]
Morning Type	12.6	13.0	[8, 16]	2.6	−0.60	2.6	[9.5, 15.0]
Intermediate Type	9.9	10.0	[2, 23]	4.6	0.80	3.9	[8.0, 11.5]

Table 7.   Summary statistics for ESS score (n = 32).

	p-value (2-tailed)	Type of Test	Statistically Significant?
Gender	0.65	Wilcoxon Rank Sum	No
Commissioning Status	0.05	Wilcoxon Rank Sum	Yes
Department	0.13	Kruskal-Wallis Rank Sum	No
Watchstation Location	0.65	Wilcoxon Rank Sum	No
CSM	0.07	Wilcoxon Rank Sum	No

Table 8.   P-value results and the name of the statistical test used for determining statistical significance (α = 0.05), with regard to the ESS score, for the variables of interest.

a.   Age

As shown in Figure 24, as participant age increased, ESS scores tended to decrease. The red line is a linear regression, which shows a slight negative correlation (ρ = –0.29) between age and ESS score. The green curve is a nonparametric "lowess" smoother, a method of locally-weighted polynomial regression. The green curve shows that as age increased, ESS score may decrease at a greater rate. A Spearman Rank Correlation Coefficient Test (α = 0.05) gives a normally approximated p-value = 0.11, indicating weak evidence of a slight negative correlation between ESS score and age. This finding was unusual, as Epworth scores generally increase with age (i.e., people experience more daytime sleepiness as they age) (Gander, Marshall, Harris, & Reid, 2005). However, this finding is explained in the next section, which compares officer and enlisted ESS score.
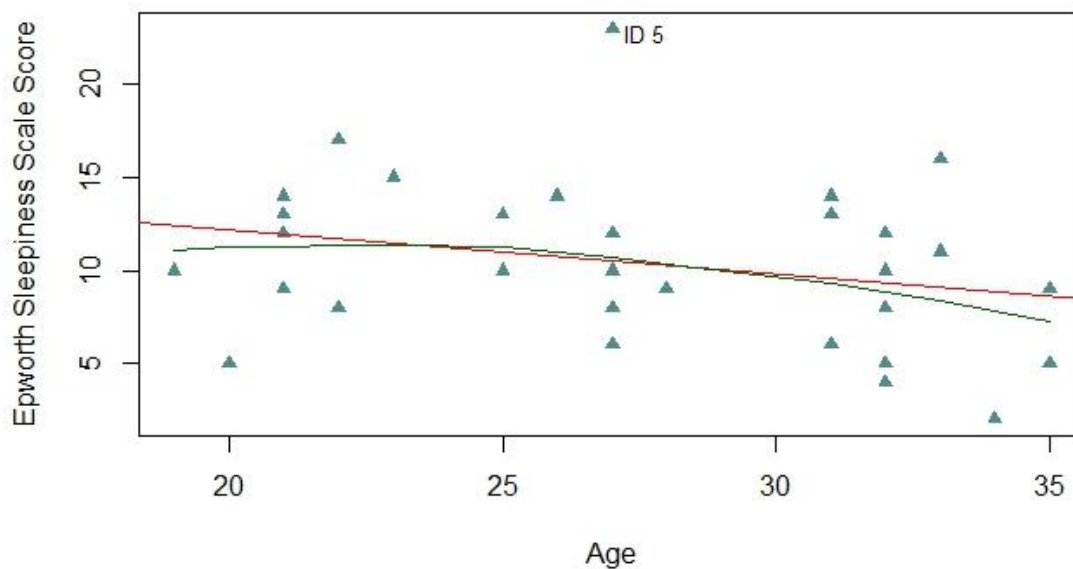
Figure 24. Scatter plot of ESS score and age with a linear regression (red) and a nonparametric lowess regression (green) of ESS as a function of age.

b. Commissioning Status

The summary statistics for ESS scores for enlisted sailors and officers are displayed in Table 7. Figure 25 provides additional information about ESS scores according to commissioning status. As shown in Table 8, the difference in scores between enlisted and officer groups was statistically significant, as officers tended to experience less daytime sleepiness than enlisted sailors. Additional results explaining possible reasons for this difference are presented in subsequent sections.
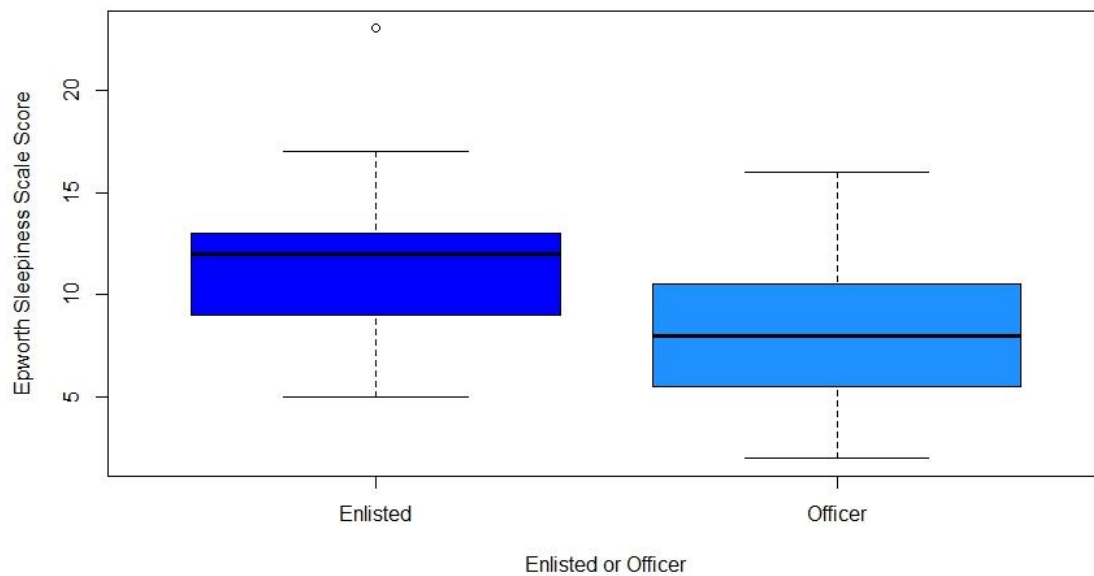
Figure 25.   Box plot of ESS scores by commissioning status.

Table 9 displays the number of enlisted and officers with elevated and normal ESS scores. There were a greater proportion of officers with normal ESS scores (73%) than enlisted (43%), which is not surprising, based on the 95% confidence intervals for the medians of enlisted and officer scores. Based on the Pearson's Chi-squared Test with simulated p-value (based on 10,000 replications, α = 0.05), however, the difference in the proportion of officers and enlisted with elevated and normal ESS scores was not statistically significant (p-value = 0.15).

	Elevated	Normal
Enlisted	12	9
Officer	3	8

Table 9.   The number of enlisted and officers with normal and elevated ESS scores.

Because both the ESS scores and ages of officer and enlisted sailors were significantly different, ESS score as a function of age, with officer and enlisted personnel separated, was also examined. Figure 26 is a plot of ESS

scores as a function of age, with enlisted and officer scores identified. Linear regressions for both officer (red) and enlisted (green) are plotted as well. Interestingly, the regressions are non-overlapping and have nearly opposite slopes in the range of ages between 18 and 35. Even though officers tended to be older than enlisted personnel in this sample, officers tended to have lower ESS scores. The effect of officers being older, yet having lower ESS scores, at least partially explains the weak overall negative correlation between age and ESS scores. For both officers and enlisted, however, there was not enough evidence to conclude that a statistically significant correlation existed between ESS score and age, as verified by Spearman Rank Correlation Tests (α = 0.05), resulting in ρ = 0.05 and a normally approximated p-value = 0.89 for officers and ρ = –0.06 and a normally approximated p-value = 0.78 for enlisted sailors.
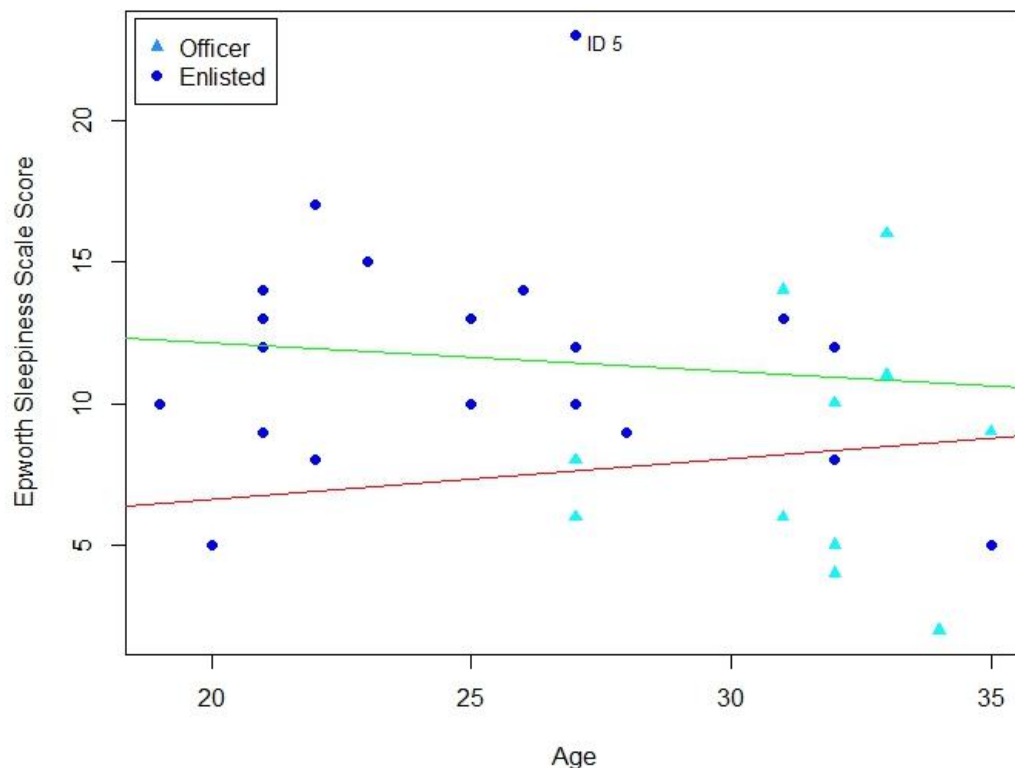
Figure 26. Scatter plot of ESS score as a function of age with separate linear regression fits for enlisted sailors (green) and officers (red).

c. Epworth Sleepiness Scale and Composite Scale of Morningness

The summary statistics for ESS scores according to CSM-determined chronotype are displayed in Table 7. Figure 27 provides additional information about ESS scores according to chronotype. The variability of the ESS scores for intermediate-type participants is higher than that of morning-type participants, although the difference in variability could simply be a function of the small number of morning-type participants. As shown in Table 8, there is statistical evidence of a difference in ESS scores between chronotypes at only the 0.07 level.
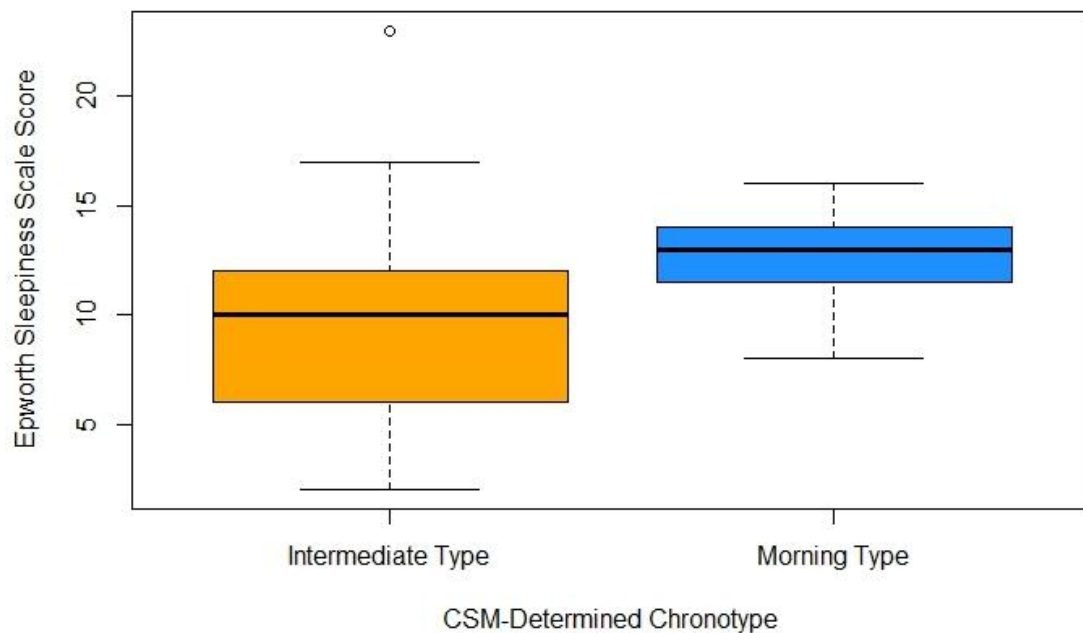
Figure 27.   Box plot of Epworth score, delineated by CSM-determined chronotype.

Table 10 displays the number of participants with elevated and normal ESS scores by chronotype. Six of seven (86%) morning-type participants reported elevated Epworth scores. The majority of intermediate-type participants (64%) reported normal ESS scores. Based on the Pearson's Chi-squared Test,

with simulated p-value (based on 10,000 replications, α = 0.05), the difference in the proportion of participants with elevated and normal Epworth scores between intermediate- and morning-types is statistically significant (p-value = 0.03).

	Elevated ESS	Normal ESS
Morning Type	6	1
Intermediate Type	9	16

Table 10.   Number of participants with elevated and normal ESS scores, grouped by chronotype.

A morning chronotype participant in this study was more likely to have an elevated ESS score, while a participant with an intermediate chronotype is more likely to have a normal ESS score. This result is comparable to past studies that found later chronotypes (i.e., intermediate or evening type) usually have a higher shiftwork tolerance, as their sleep-wake behavior is less rigid (i.e., show greater circadian flexibility) than earlier types and they accumulate less sleep debt during a shiftwork cycle (Duffy, Dijk, Hall, & Czeisler, 1999; Foster & Kreitzman, 2004; Harma, Tenkanen, Sjoblom, Alikoski, & Heinsalmi, 1998; Ostberg, 1973). Accumulating less sleep debt corresponds to less daytime sleepiness and lower ESS scores. This result suggests two important issues: (1) individuals with greater circadian flexibility (i.e., individuals with intermediate chronotype) experience less daytime sleepiness in naval operational environments; and (2) individuals' chronotypes in operational units could be a tool for identifying officers and sailors with greater susceptibility to sleep-induced fatigue, thus providing the command and individuals with a greater awareness of their sleep needs. These results warrant further research in follow-on studies.

7.   Composite Scale of Morningness

The different categories of chronotype and their relationship to CSM score are described in Chapter I, Section G. Although, at α = 0.05, the Shapiro-Wilk Test for normality (p-value = 0.19) does not provide evidence that CSM scores

are not normally distributed, the distribution of CSM scores in Figure 28 does not appear normal. Hence, it should not be assumed that CSM scores are normally distributed in this analysis. Overall, 25 participants were intermediate type and seven were morning type, while none were evening type.
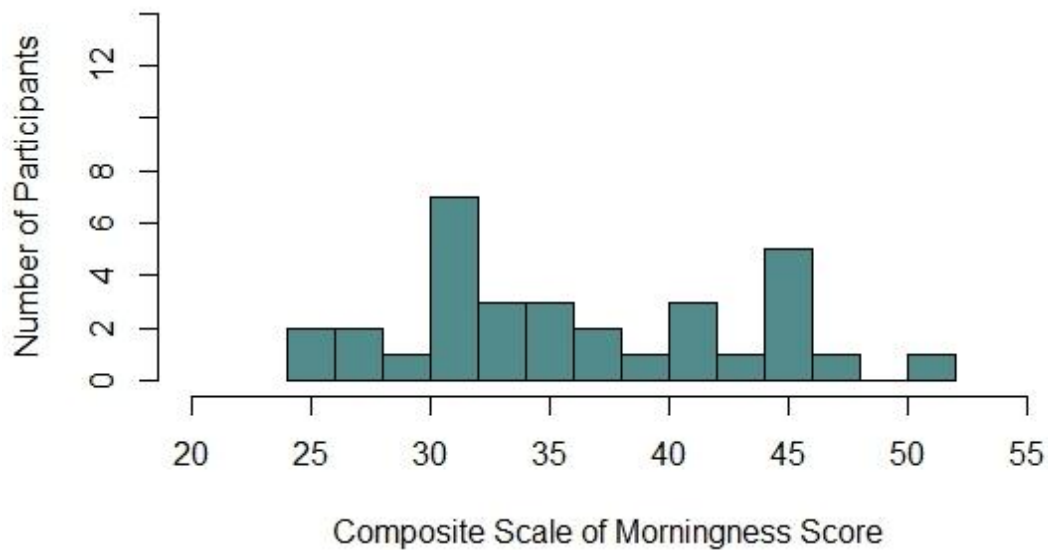
Figure 28.   Distribution of CSM scores for all participants.

In order to gain better insight into any potential differences in CSM scores among different demographic groups, CSM scores were examined according to age, gender, commissioning status, department, and watchstation location. The summary statistics for CSM scores are displayed in Table 11. Table 12 presents the two-tailed p-value and the name of the statistical test used for each of the tests of statistical significance conducted, with regard to CSM score, for the different variables of interest.

	Mean	Median	Range	Std Dev	Skewness	Kurtosis	Confidence Interval (95%)
All Participants	36.6	35.0	[25, 52]	7.1	0.3	2.1	[33.5, 39.0]
Male	36.2	34.0	[25, 48]	6.6	0.3	1.9	[32.5, 39.0]
Female	37.9	38.0	[25, 52]	9.2	0.1	2.0	[28.0, 46.5]
Enlisted	35.3	34.0	[26, 48]	6.5	0.6	2.3	[32.0, 38.5]
Officer	38.9	41.0	[25, 52]	7.8	–0.2	2.3	[33.0, 44.0]
Reactor	33.6	31.5	[26, 48]	6.5	1.2	3.4	[29.5, 38.0]
Deck	38.9	38.0	[32, 46]	5.3	0.2	1.6	[33.5, 45.5]
Belowdecks	34.7	33.5	[25, 48]	6.7	0.1	2.0	[31.0, 38.0]
Topside	39.8	40.5	[31, 52]	6.8	0.6	2.3	[35.5, 45.0]

Table 11.   Summary statistics for CSM score (n = 32).

	p-value (2-tailed)	Type of Test	Statistically Significant?
Gender	0.68	Wilcoxon Rank Sum	No
Commissioning Status	0.25	Wilcoxon Rank Sum	No
Department	0.08	Kruskal-Wallis Rank Sum	No
Watchstation Location	0.07	Wilcoxon Rank Sum	No

Table 12.   P-value results and the name of the statistical test used for determining statistical significance (α = 0.05), with regard to CSM score, for the variables of interest.

a.   Age

As shown in Figure 29, there was little relationship between age and CSM score. The red line is a linear regression, which shows that no correlation ($\rho = -0.08$) existed between age and CSM score. The green lowess smoother shows that CSM score initially decreased as age increased, but then started to increase at around 26 years old. This result is surprising because several studies have shown that CSM actually increases as one ages (i.e., a person begins to naturally trend toward "morningness") (Duffy & Czeisler, 2002; Roenneberg, Justice, & Merrow, 2003). Subsequent analysis attempts to explain a possible reason for the weak correlation between CSM score and age.
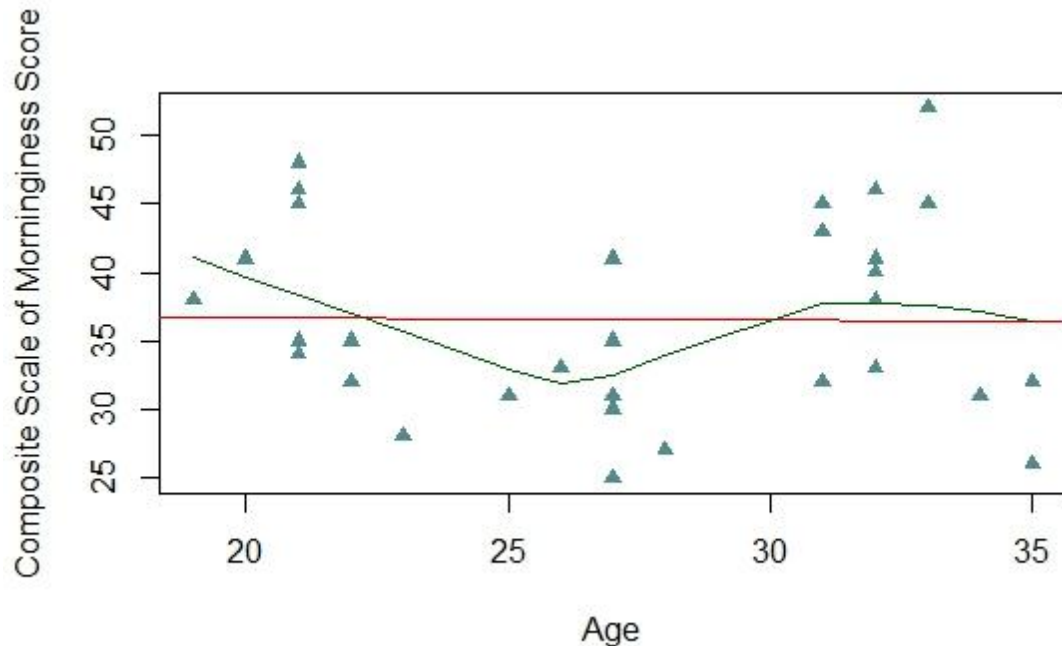
Figure 29. Scatter plot of CSM score and age with a linear regression (red) and a nonparametric lowess regression (green) of CSM score as a function of age.

Linear regression fits of CSM score as a function of age for both officer (red) and enlisted (green) are plotted in Figure 30. For officers, the Spearman Rank Correlation Test (α = 0.05), with ρ = –0.03 and normally approximated p-value = 0.93, indicated that there was no statistical correlation between CSM score and age. On the other hand, for enlisted sailors, the Spearman Rank Correlation Test (α = 0.05), with ρ = –0.48 and normally approximated p-value = 0.03, indicated that there was a negative statistical correlation between CSM score and age.
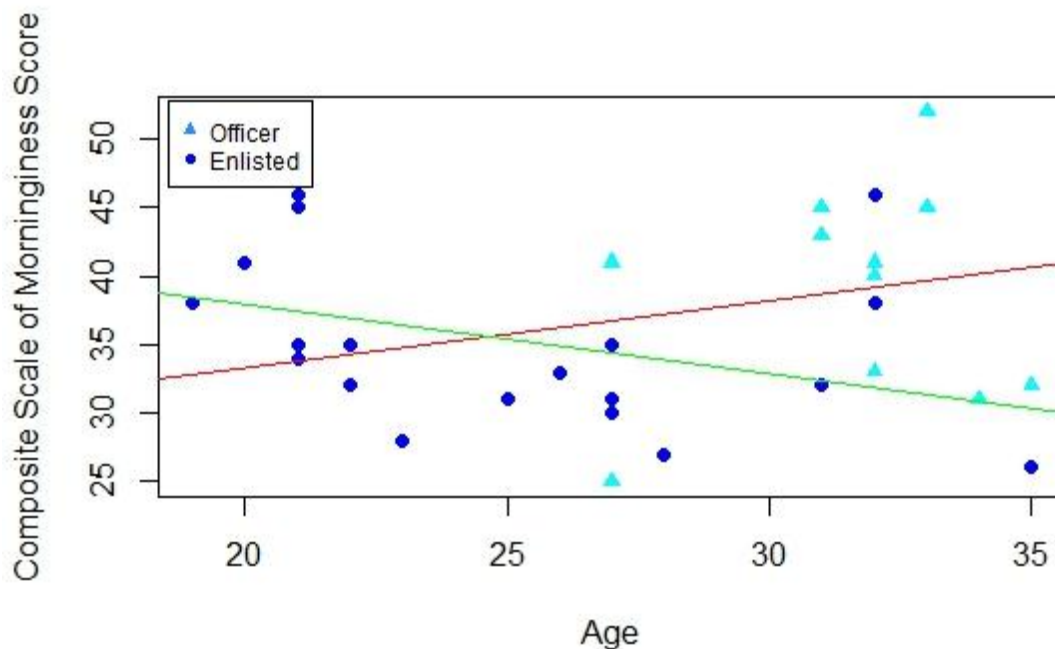
Figure 30.   Plot of CSM scores as a function of age, with separate linear
regression fits for officers (red) and enlisted sailors (green).

The conflicting results of CSM scores (i.e., strongly decreasing with age for enlisted sailors and having no relationship with age for officers) may have accounted for the overall weak correlation between age and CSM score. Additionally, the negative correlation between age and CSM score for enlisted participants is unusual in that CSM score, after reaching an eveningness trough in early adulthood, tends to increase with age (Carrier, Monk, Buysse, & Kupfer, 1997). In this thesis, however, although most young enlisted personnel tended to be intermediate type, they were closer to being morning than evening type. Furthermore, older enlisted sailors' CSM scores tended to be closer to the center of the intermediate-type category range. Perhaps this suggests some form of psychological conditioning that occurs over time, influencing one to believe they are intermediate chronotype when they truly are not. This phenomenon is referred to as cognitive dissonance reduction, or the attempt to reduce psychological discomfort in order to reestablish internal consistency (Festinger, 1962). Another possible explanation is that people of intermediate chronotype

are simply more likely to remain in the Navy, while those of other chronotypes, with less circadian flexibility, are unable to adapt to the rotating sleep and work schedules used in an operational unit. As a result, individuals with morning and evening chronotypes may decide to get out of the Navy earlier in their careers. This attrition effect may be more prevalent with enlisted sailors because they assume more arduous rotating shift schedules, with greater frequency, than officers.

b. Department

The summary statistics for CSM scores for each department are displayed in Table 11. Figure 31 provides additional information for CSM scores according to department. As shown in Table 12, the difference in CSM score between departments is significant at only the p-value = 0.08 level.
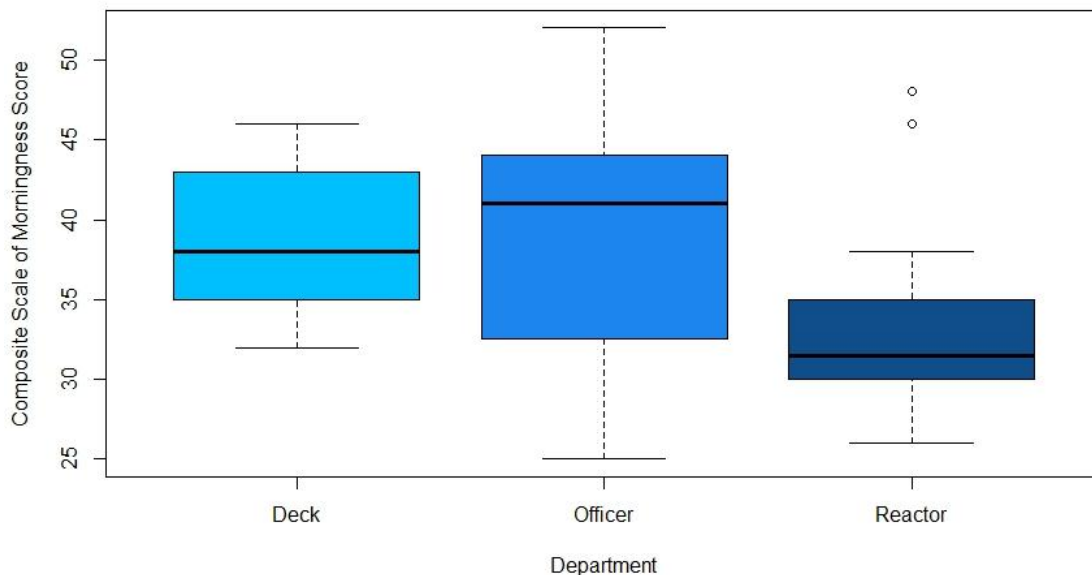
Figure 31.   Boxplot of CSM score, delineated by department.

One possible explanation for the weak statistical difference in CSM score between watchstation location and departments is that all Reactor Department watchstanders stood watch belowdecks and received only artificial light

exposure. Thus, perhaps as a result of losing the natural *zeitgeber* of daylight, participants in the Reactor Department attempted to psychologically adapt through cognitive dissonance reduction in order to make them feel as if they had less of a propensity toward either the morning or evening extremes. Another possible explanation will be explored in the next section, which examines CSM score and watchstation location. In future studies, a designed experiment approach should be used to further investigate this finding.

c.   *Location of Watchstation*

The summary statistics for CSM scores for belowdecks and topside watchstanders are displayed in Table 11. Figure 32 provides additional information about CSM scores according to watchstation location. As shown in Table 12, the difference in CSM scores between watchstation locations was statistically significant at the p-value = 0.07 level.
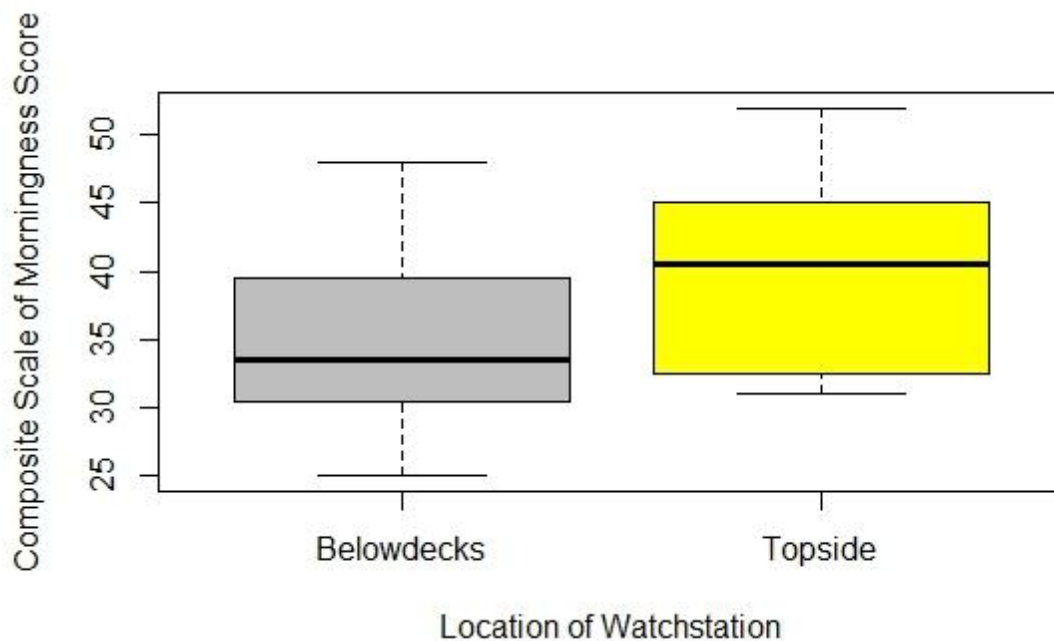
Figure 32.   Boxplot of CSM scores, delineated by watchstation location.

This result suggests that exposure to sunlight while on watch may have an effect on one's circadian entrainment. Several studies have shown that the human circadian clock is predominantly entrained by sun time, rather than social time cues (Roenneberg, Daan, & Merrow, 2003; Roenneberg & Kumar, 2007; Wright et al., 2013). Thus, when the circadian clock becomes uncoupled from sun time, the overall *zeitgeber* strength is reduced, which leads to later chronotypes (Roenneberg & Kumar, 2007). This hypothesis at least partially explains the lower CSM scores (more toward eveningness) associated with the belowdecks watchstanders and the Reactor Department. These results warrant further investigation in follow-on studies.

C.   ANALYSIS OF ACTIGRAPHY DATA

Average daily sleep for 32 participants was examined with respect to age, gender, commissioning status, department, watchstation location, and ESS and CSM scores. Day-to-day sleep (each 24-hour period) was examined in order to determine potential differences in sleep consistency between participants and departments, and to investigate any day-of-the-week effects on participant sleep. Exact confidence intervals are provided in the table of summary statistics in the following sections for the median of the average daily sleep according to the variables of interest for that section as calculated by Wilcoxon Signed Rank Tests, unless otherwise noted. Additionally, all Wilcoxon Rank Sum Tests provide exact p-values.

1.   Average Daily Sleep

Figure 33 displays a histogram of average daily sleep for the 32 participants. The data appear to be somewhat normally distributed. Based on the Lilliefors Normality Test (α = 0.05), there is not enough evidence to conclude that the data is non-normally distributed (p-value = 0.11). Due to the relatively small sample size and the heavy tails of the Normal Quantile-Quantile (Q-Q) plot shown in Figure 34, however, non-normality is more likely and average daily sleep was not assumed to have a normal distribution.
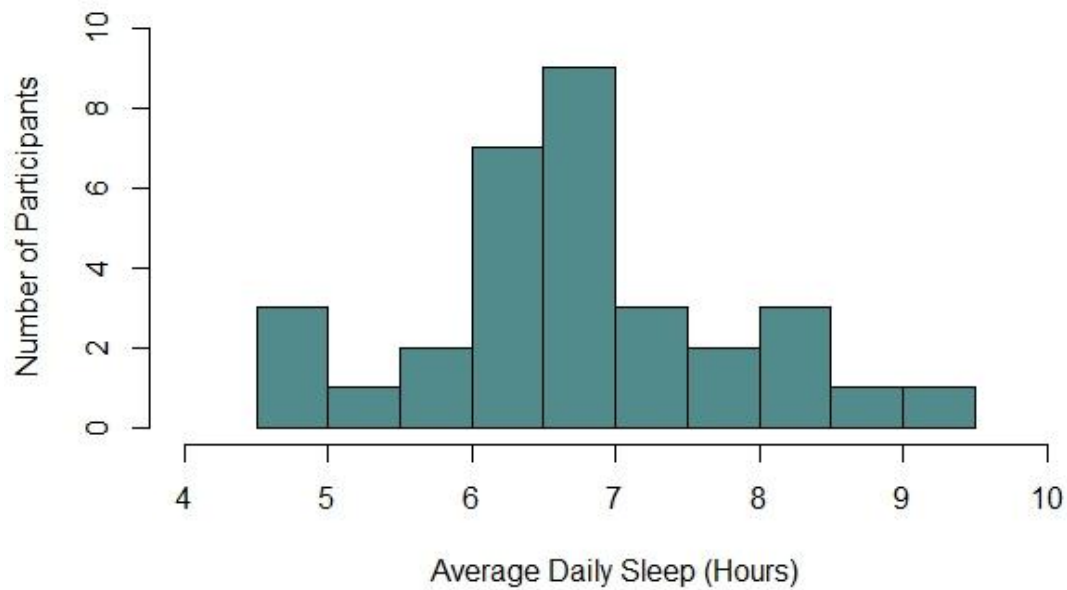
Figure 33.   Histogram of average daily sleep for all 32 participants.
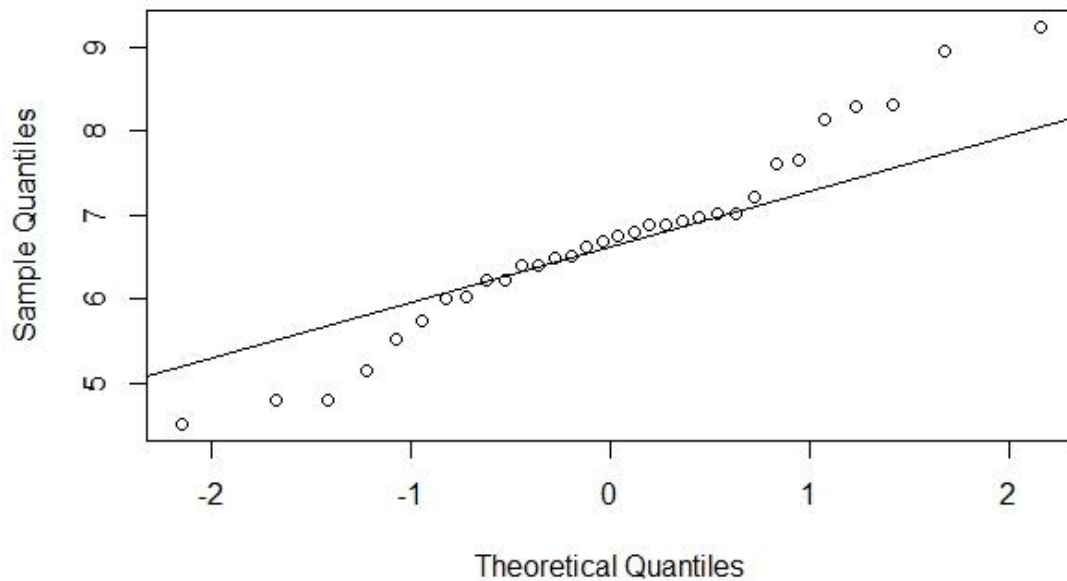
Figure 34.   Normal Q-Q plot of average daily sleep data for all 32 participants.

In order to gain better insight into any potential differences among different demographic groups, average daily sleep was examined according to age, gender, commissioning status, department, and watchstation location. Average

daily sleep was also analyzed with regard to chronotype and ESS category. The summary statistics for average daily sleep are displayed in Table 13. Table 14 presents the two-tailed p-value and the name of the statistical test used for each of the tests of statistical significance conducted, with regard to average daily sleep, for the different variables of interest.

	Mean	Median	Range	Std Dev	Skewness	Kurtosis	Confidence Interval (95%)
All Participants	6.7	6.7	[4.5, 9.2]	1.1	0.20	3.0	[6.3, 7.1]
Male	6.6	6.5	[4.5, 9.2]	1.2	0.40	2.9	[6.1, 7.0]
Female	7.1	6.9	[6.0, 8.1]	0.7	0.02	1.9	[6.4, 7.9]
Enlisted	6.5	6.7	[4.5, 8.3]	1.0	−0.20	2.5	[6.0, 7.0]
Officer	7.1	6.9	[5.2, 9.2]	1.2	0.40	2.3	[6.4, 8.0]
Reactor	6.4	6.5	[4.5, 8.3]	0.9	0.01	4.0	[6.0, 6.8]
Deck	6.7	7.0	[4.8, 8.1]	1.4	−0.60	1.8	[4.8, 7.9]
Belowdecks	6.5	6.7	[4.5, 8.3]	0.9	−0.50	3.3	[6.1, 6.9]
Topside	7.1	6.8	[4.8, 9.2]	1.4	2.00	0.9	[6.2, 8.0]
Morning Type	5.9	5.7	[4.5, 8.1]	1.3	0.60	2.3	[4.8, 7.3]
Intermediate Type	6.9	6.9	[4.8, 9.2	1.0	0.50	3.4	[6.5, 7.3]
Elevated ESS	6.2	6.4	[4.5, 8.1]	1.1	0.01	2.2	[5.6, 6.7]
Normal ESS	7.2	6.9	[5.7, 9.2]	1.0	0.70	2.6	[6.6, 7.7]

Table 13.   Summary statistics for average daily sleep (hours per day) (n = 32).

	p-value (2-tailed)	Type of Test	Statistically Significant?
Gender	0.30	Wilcoxon Rank Sum	No
Commissioning Status	0.20	Wilcoxon Rank Sum	No
Department	0.30	Kruskal-Wallis Rank Sum	No
Watchstation Location	0.40	Wilcoxon Rank Sum	No
ESS	0.01	Wilcoxon Rank Sum	Yes
CSM	0.04	Wilcoxon Rank Sum	Yes

Table 14.   P-value results and the name of the statistical test used for determining statistical significance (α = 0.05) for average daily sleep for the variables of interest.

a.   Epworth Sleepiness Scale

The summary statistics for average daily sleep by ESS category are displayed in Table 13. Figure 35 provides additional information about the average daily sleep of participants in the different ESS categories. As shown in

Table 13 and Table 14, participants with normal ESS scores received statistically significantly more average daily sleep than those with elevated ESSs.
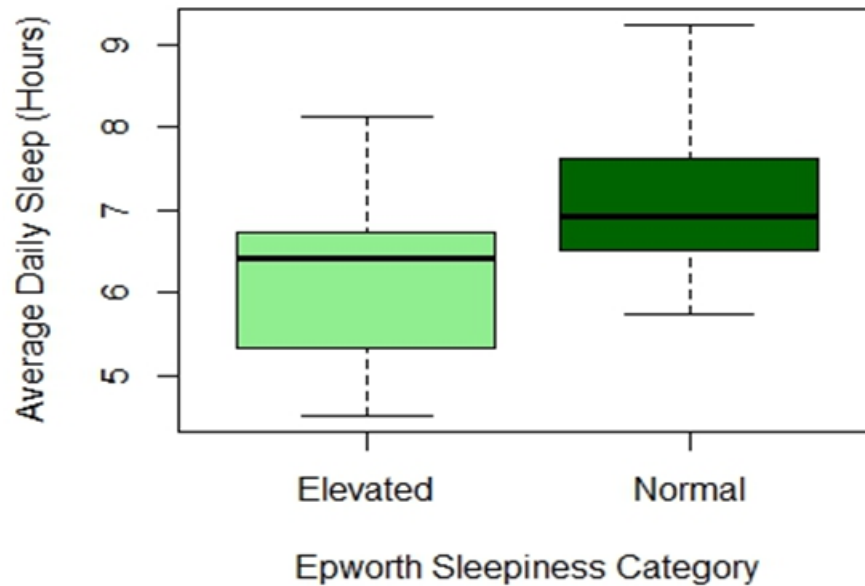
Figure 35.   Average daily sleep by ESS category.

This finding is consistent with a prior study conducted by Shattuck and Matsangas (2014) which found that ESS scores were related to the amount of daily sleep and mean reaction time, as measured by PVT. Because the ESS questionnaire is simple and takes only two to three minutes to administer, yet can accurately identify individuals suffering from sleep deprivation, it provides a unique tool that naval units can employ to identify at-risk individuals. Thus, sleep countermeasures can be efficiently and expeditiously administered to those suffering from sleep-induced fatigue without the need for issuing costly actigraphy devices to all personnel in operational units.

b.   *Composite Scale of Morningness*

The summary statistics for average daily sleep according to CSM-determined chronotype are displayed in Table 13. Figure 36 provides additional

information about average daily sleep based on chronotype. As shown in Table 14, the difference in average daily sleep between participants of morning and intermediate chronotype was statistically significant.
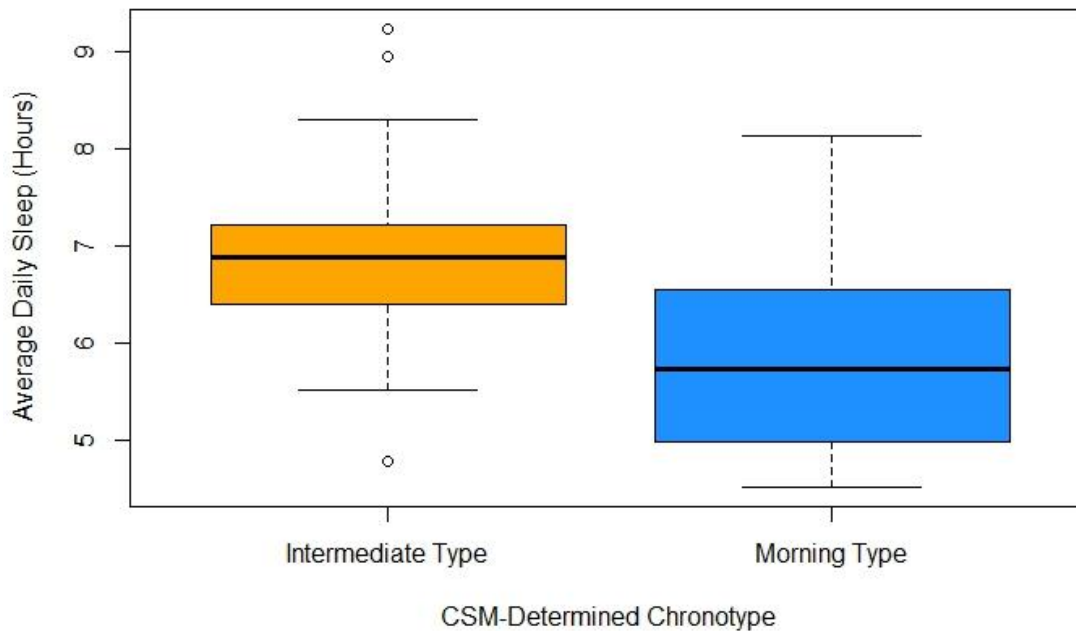
Figure 36.   Average daily sleep by CSM-determined chronotype.

Participants in this study with a morning chronotype tended to receive less sleep than participants with an intermediate chronotype. This finding suggests that individuals with greater circadian flexibility (i.e., those with intermediate chronotypes) are more likely to receive a greater amount of average daily sleep in Navy operational environments. The statistically significant difference in average daily sleep between intermediate- and morning-type participants is consistent with past studies that found later chronotypes usually have a higher shiftwork tolerance, as their sleep-wake behavior is less rigid than earlier types, and that they accumulate less sleep debt during a shiftwork cycle (Duffy, Dijk, Hall, & Czeisler, 1999; Foster & Kreitzman, 2004; Harma, Tenkanen, Sjoblom,

Alikoski, & Heinsalmi, 1998; Ostberg, 1973). However, participants with intermediate chronotypes still experienced sleep deprivation during the course of this study.

2.   Day-to-Day Sleep

The day-to-day sleep of participants was investigated in order to gain additional insight into their sleep habits. Furthermore, analyzing day-to-day sleep provided for an investigation of the variability of each participant's daily sleep not yet accounted for by the average daily sleep analysis. A "day," for the purposes of this analysis, was considered as 0000-2359. Since the study was executed during three different, but overlapping periods, each period was analyzed separately and then compared, in order to determine any possible differences or similarities between the different periods. The three different periods, August 26-September 10, September 4-September 16, and September 11-September 23, are referred to as Periods 1, 2, and 3, respectively. Period 1 consisted of participants from the Reactor Department and one officer standing watch in the reactor plant spaces; Period 2 consisted of only officers; and Period 3 consisted of enlisted sailors in the Deck Department. Because not all participants participated in the study for the same number of days, each period was standardized so that the maximum number of participants and the maximum number of days could be considered for each period. Participant 23 was removed from this portion of the analysis, due to participating in the study for fewer days than all other participants. Thus, 31 participants were included in the analysis of day-to-day sleep.

a.   Period 1

Period 1 consisted of mainly enlisted sailors from the Reactor Department. One officer participated during this period, but stood watch in the reactor plant spaces and followed a 5ON/15OFF watch schedule. Fifteen crewmembers participated in Period 1. During this period, the ship conducted flight operations while transiting the Arabian Sea and transited Bab el-Mandeb Strait into the Red

Sea in order to support U.S. national interests in the Middle East. The Reactor Department, as discussed in Chapter IV, Section B, used a four-section 5ON/15OFF watch schedule, carried out training several times per week, and executed drills at least five nights per week between 0200 and 0700. Sunday was generally designated as an "off" day when the department followed a "holiday" routine. This general schedule is considered standard for aircraft carrier reactor departments while deployed at sea.

The day-to-day sleep of each participant was investigated. A plot similar to that shown for Participant 6, in Figure 37, was generated for each participant (see Appendix F for plots for all other participants). Clearly this sailor's day-to-day sleep was highly inconsistent. Nearly all of the participants experienced inconsistent day-to-day sleep throughout the study period; however, additional insight can be gained by investigating the variance of participants' daily sleep.
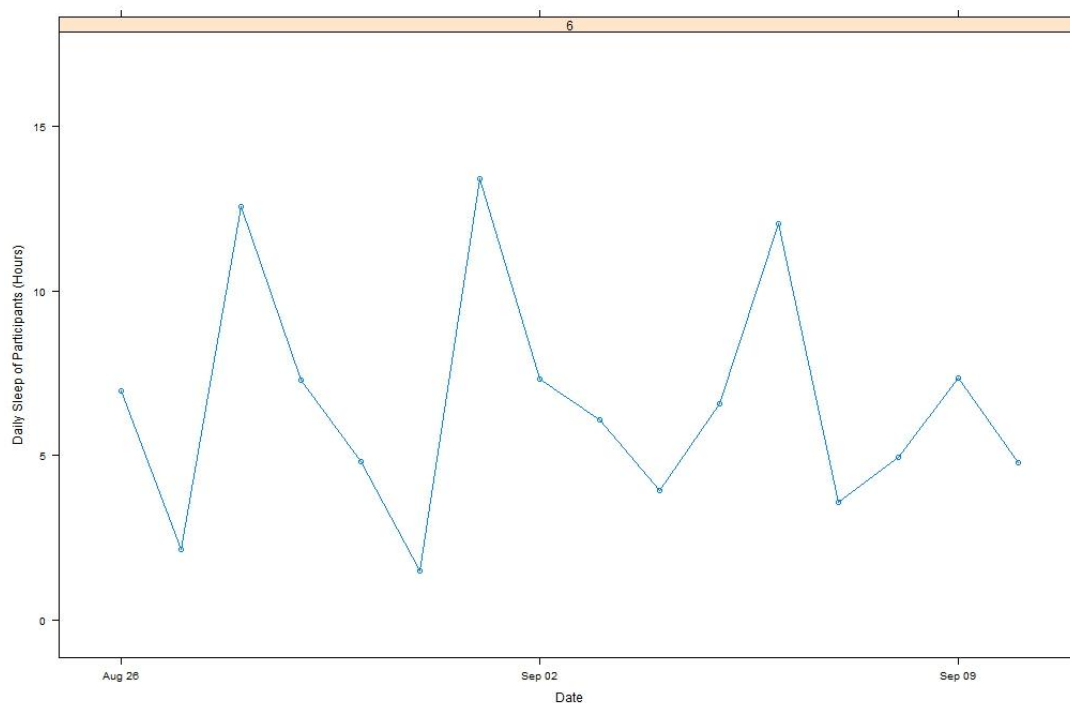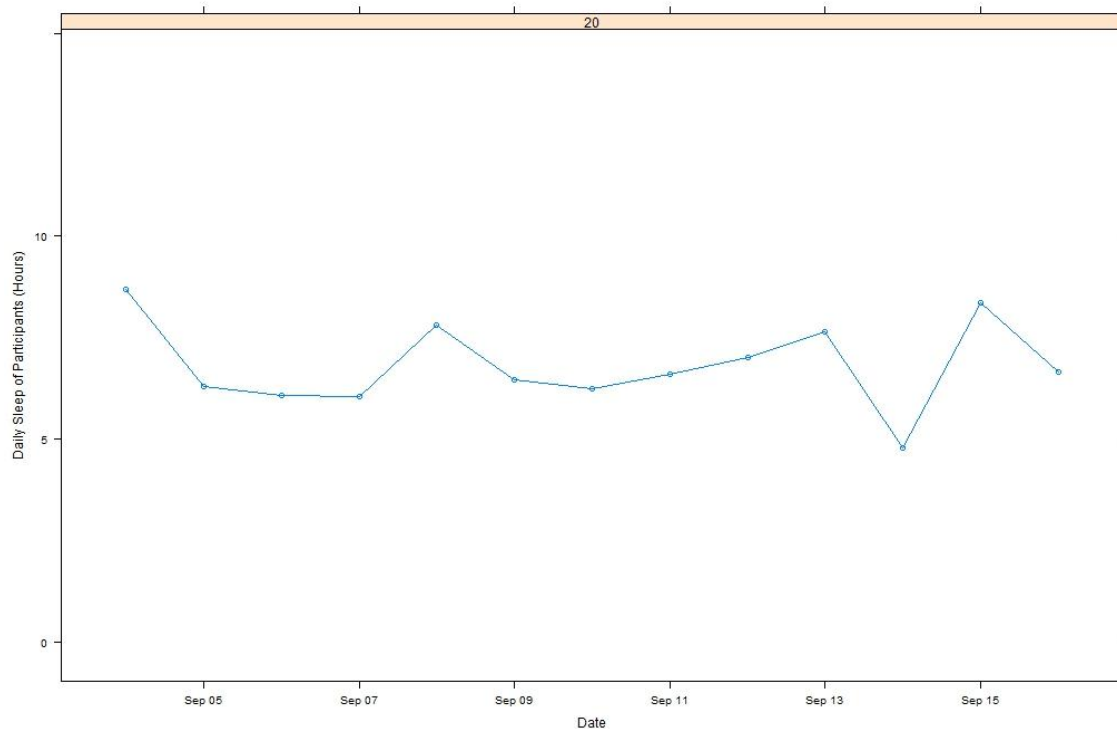

Figure 37.   Day-to-day sleep of Participant 6.

As shown in Figure 38, the variability in day-to-day sleep for each participant was large and the day-to-day sleep of some participants, most notably ID12 and ID13, appears to vary much less than the other participants during this period. However, when comparing the day-to-day sleep of the 15 participants from Period 1, according to the Fligner-Killeen Test of Homogeneity of Variances (α = 0.05), there is not enough evidence to conclude that the variances of the participants' daily sleep were statistically different (p-value = 0.49).
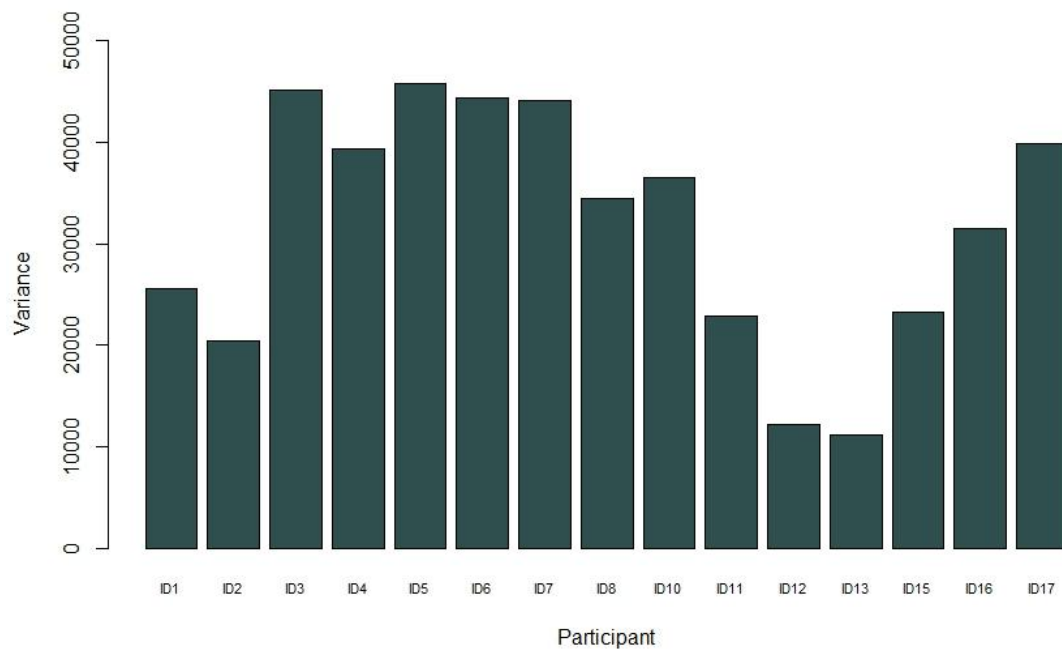
Figure 38.   Variance of day-to-day sleep for participants of Period 1.

Of note, ID12 was the only officer that participated during Period 1 and ID13 was a Petty Officer First Class Machinist's Mate (Nuclear). The officer did not have any collateral duties or responsibilities, while the petty officer was the Leading Petty Officer of one of the two Reactor Mechanical Divisions, a key enlisted leadership position within the Reactor Department. Additionally, both stood supervisory watches. Interestingly, ID12 slept, on average, 7 hours per day, while ID13 slept only 5.7 hours per day. Thus, even though both participants

experienced relatively consistent sleep compared to the other participants during Period 1, ID13 slept over 1.25 hours less per night than ID12. Additionally, ID7, a Petty Officer Third Class Machinist's Mate (Nuclear), whose day-to-day sleep varied tremendously, received the greatest average daily sleep, 8.3 hours, of all Period 1 participants.

Figure 39 displays average daily sleep as a function of the variance of each participant's day-to-day sleep. The red lowess fit shows that average daily sleep is relatively constant as a function of the variance of day-to-day sleep. Based on a Spearman Rank Correlation Test (α = 0.05) with ρ = −0.09 and p-value = 0.76, there is not enough evidence to conclude that a statistical correlation existed between average daily sleep and sleep consistency. Sleep consistency had little effect on the actual amount of daily sleep participants received during Period 1. Regardless of the inconsistent nature of sailor sleep, most participants received not only too little sleep, but experienced large fluctuations in their day-to-day sleep. Furthermore, in an attempt to recover from severe bouts of sleep debt, many participants relied upon "binge sleeping," or sleep periods in excess of 8-9 hours.
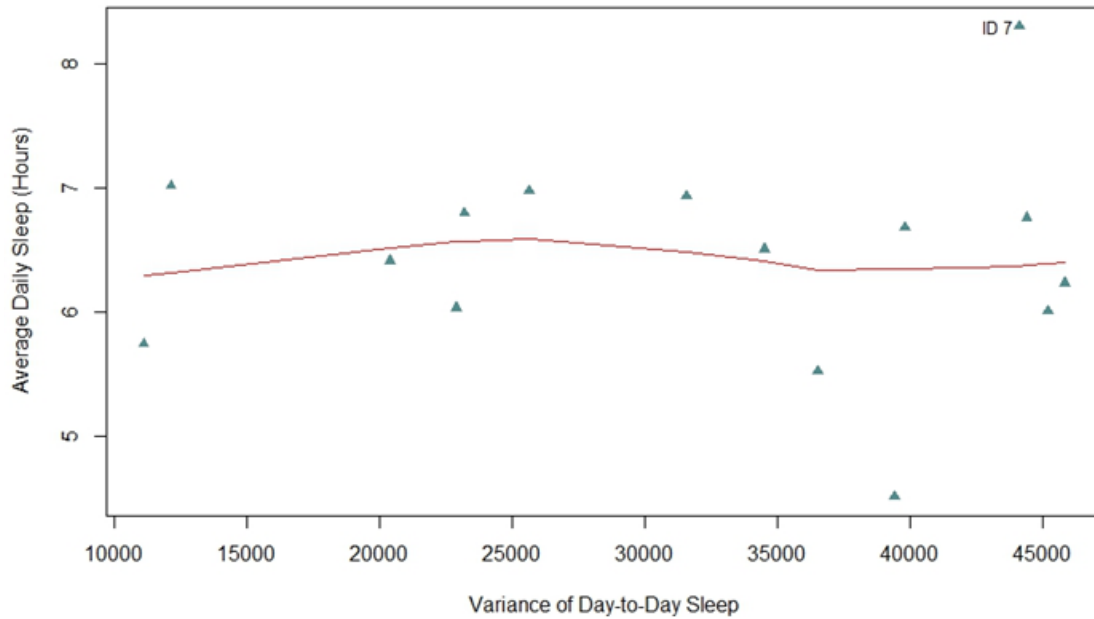
Figure 39.   Scatter plot of average daily sleep as a function of the variance of day-to-day sleep for Period 1.

Figure 40 displays the average day-to-day sleep of the participants of Period 1. Each point represents the average sleep of the 15 participants for that day. This plot visually illustrates the lack of pattern, or trend, in the average sleep of the Reactor Department. Of note, on two occasions, Monday, August 26 and Saturday, August 31, the participants averaged less than five hours of sleep. This indicates that the participants, as a whole, experienced severe sleep deprivation during these two days.
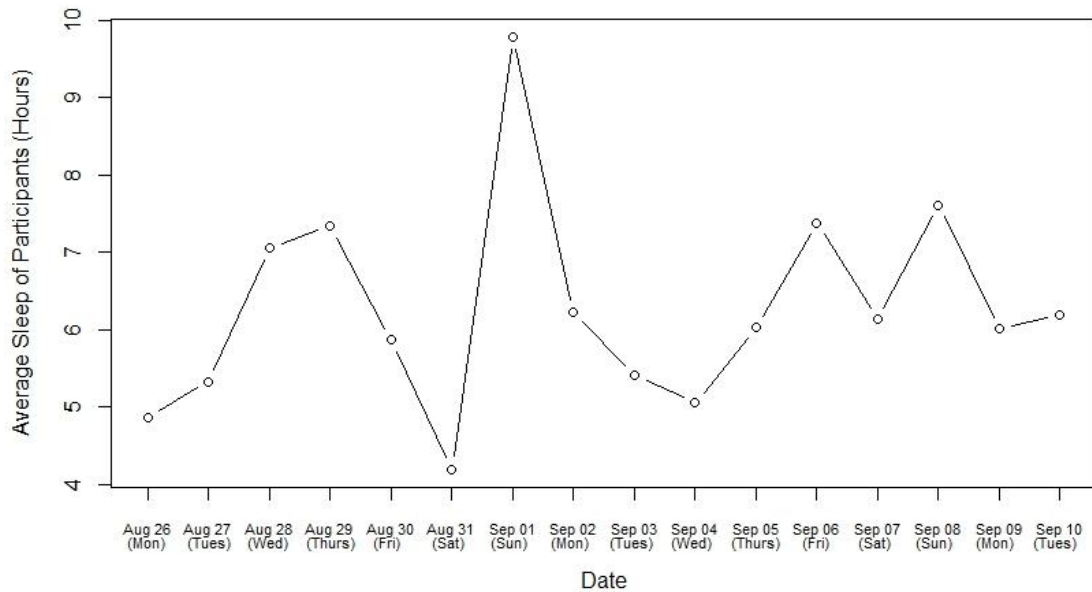
Figure 40.   Average day-to-day sleep of the 15 participants of Period 1.

Also of significance was the substantially greater amount of average sleep the participants received on Sunday. Based on a Kruskal Wallis Rank Sum Test (α = .05), there was a day-of-the-week effect in the day-to-day sleep of the participants of Period 1 (p-value = 0.003). There was a statistically significant difference between the days of the week with regard to the average amount of sleep that the participants received. Based on a pairwise Multiple Comparison Wilcoxon Rank Sum Test using the Holm's p-value adjustment procedure (family-wide α = 0.05), there was strong statistical evidence to conclude that a difference in the average sleep of participants existed between Sunday and Monday, Sunday and Tuesday, and Sunday and Saturday. Table 15 displays the p-values for all of the pairwise comparisons.

	Friday	Monday	Saturday	Sunday	Thursday	Tuesday
Monday	1.00	-	-	-	-	-
Saturday	1.00	1.00	-	-	-	-
Sunday	0.28	0.01	0.02	-	-	-
Thursday	1.00	1.00	1.00	0.40	-	-
Tuesday	1.00	1.00	1.00	0.02	1.00	-
Wednesda	1.00	1.00	1.00	0.09	1.00	1.00

Table 15.   P-values of all pairwise comparisons for the average sleep of the 15
participants with regard to the day of the week. The
p-values of significance are highlighted in orange.

The results of Period 1 suggest the following four critical issues: (1) in an operational aircraft carrier's Reactor Department, day-to-day sleep is highly inconsistent; (2) there is little connection between sleep consistency and the average daily sleep of Reactor Department personnel; (3) the Reactor Department routinely forced participants into severe sleep debt multiple times per week; and (4) the Reactor Department, in following a "holiday" routine on Sunday, relied upon Sunday as a day for its personnel to recover from a week of sleep deprivation. Participants were often going 24–48 hours with little to no sleep, and then were "binge sleeping" in excess of 8–9 hours in an attempt to recuperate. As shown by several studies, however, a single sleep episode in excess of 8–9 hours is not enough to fully recover from several days of sleep deprivation (Belenky et al, 2003; Dinges et al., 1997; Van Dongen, Maislin, et al., 2003; Van Dongen, Rogers, et al., 2003). The study conducted by Belenky et al. (2003) at the WRAIR showed that three days of recuperative sleep was still not enough to recover the performance decrements suffered as a result of sleep deprivation. Thus, participants in Period 1 were certainly experiencing sleep deprivation and chronic sleep debt, while they were also not being provided an opportunity to adequately recuperate. These consequences pose severe health and safety risks to the Reactor Department of the USS *Nimitz*.

b. *Period 2*

Period 2 consisted of eight officers standing watch on the bridge as Officer of the Deck (OOD), Junior Officer of the Deck (JOOD), or Junior Officer of the Watch (JOOW) and one officer standing watch in the Combat Information Center (CIC). During Period 2, the ship operated in the Red Sea in order to support U.S. national interests in the Middle East. Officers standing bridge and CIC watches, as discussed in Chapter IV, Section B, used a six-section 4ON/20OFF watch schedule. Two of the officers were Division Officers and one was a Department Training Officer, while the rest had no collateral duties.

The day-to-day sleep of each participant was investigated. A plot similar to that shown for Participant 20, in Figure 41, was generated for each participant. As compared to the participants of Period 1, the day-to-day sleep of those in Period 2 seemed to be less variable overall. Some participants in Period 2, however, experienced consistent sleep, while the day-to-day sleep of others varied widely. Additional insight was gained by investigating the variance of participants' daily sleep.

Figure 41.   Day-to-day sleep of Participant 20.

As shown in Figure 42, the variability in the day-to-day sleep for some participants was large and, for some participants, most notably ID20 and ID21, day-to-day sleep appears to vary much less than that of the other participants. Unlike the participants of Period 1, when comparing the day-to-day sleep of the nine participants from Period 2, according to the Fligner-Killeen Test of Homogeneity of Variances (α = 0.05), the variance of participants' day-to-day sleep was statistically different (p-value = 0.03). In other words, the consistency of day-to-day sleep for the participants of Period 2 was different. Some officers' sleep varied widely on a daily basis, while others received relatively consistent day-to-day sleep.
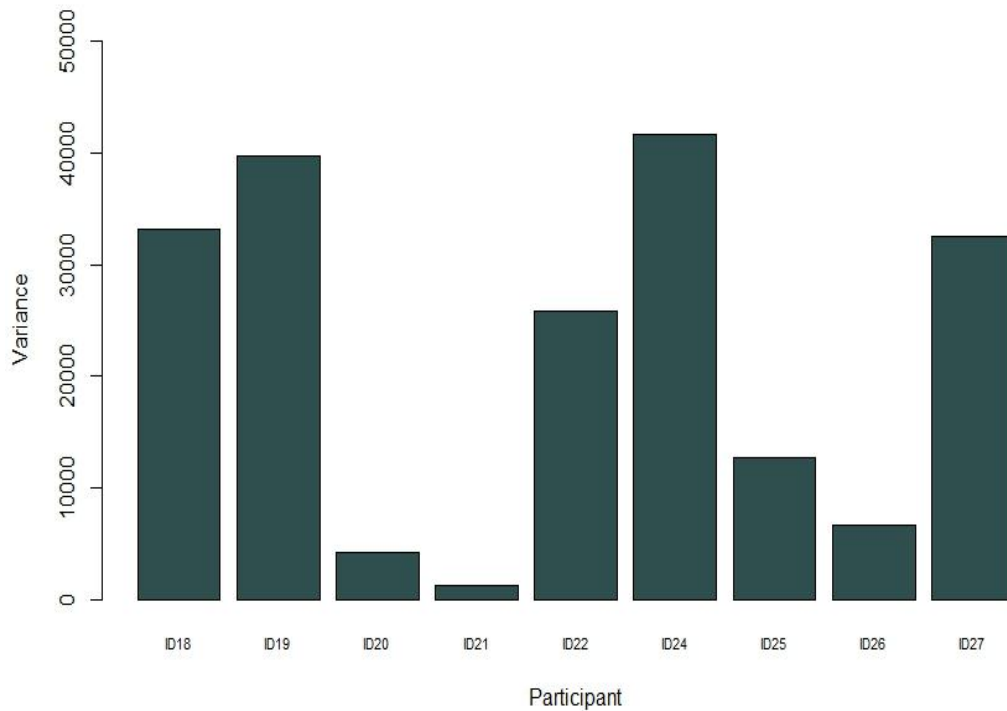
Figure 42.   Variance of day-to-day sleep for participants from Period 2.

Of note, ID20 was a Division Officer in the Operations Department, a key leadership position, while ID21 did not have any collateral duties. Furthermore, ID20 averaged 7.2 hours of sleep per day, while ID21 averaged only 6.6 hours. Thus, even though both participants experienced relatively consistent sleep as compared to others in Period 2, ID20 slept nearly 40 minutes longer, on average, than ID21. Yet, ID19—an officer who stood JOOD on the Bridge and did not have a collateral duty, averaged 8.9 hours of sleep per day, the second most of any participant in the entire study across all periods—experienced the second most inconsistent sleep out of all the participants in Period 2.

Figure 43 displays average daily sleep as a function of the variance of each participant's day-to-day sleep. The red lowess fit shows that average daily sleep is relatively constant as a function of the variance of day-to-day sleep. Based on a Spearman Rank Correlation Test (α = 0.05), with ρ = 0.10 and p-value = 0.81, there is not enough evidence to conclude that a correlation existed

between average daily sleep and sleep consistency. Sleep consistency had little effect on the actual amount of daily sleep that sailors received in Period 2.
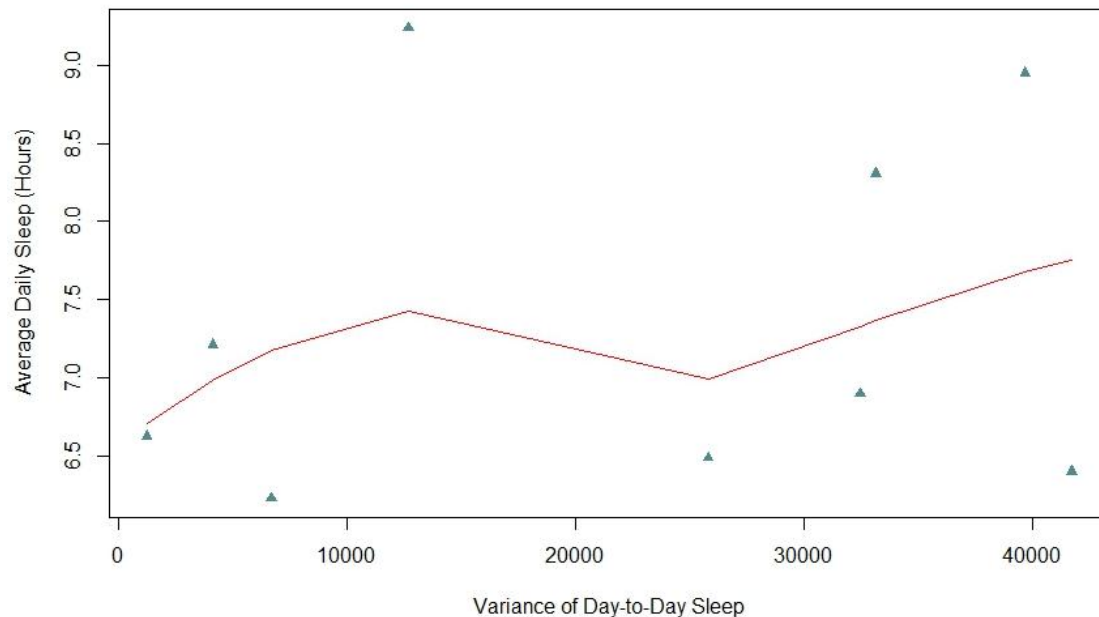
Figure 43. Scatter plot of average daily sleep as a function of participant day-to-day sleep variance for Period 2.

Figure 44 displays the average day-to-day sleep of the participants of Period 2. Each point represents the average sleep of the nine participants for that day. Although the average sleep of the participants in Period 2 changed substantially day-to-day, it appears to do so less than that for the participants in Period 1. Based on the one-tailed Mood Test for Equality of Variance (α = 0.05), there is strong statistical evidence to conclude that the day-to-day sleep of participants from Period 1 is more variable (less consistent) than that of participants from Period 2 (p-value = 0.03). This result suggests that officers, often given more autonomy and control of their own daily schedule, experienced greater consistency in their daily sleep. Although, the average daily sleep of officers was not statistically significantly greater than that of the sailors in the

Reactor Department, having greater control over one's schedule (including sleep) may have contributed to more consistent day-to-day sleep.
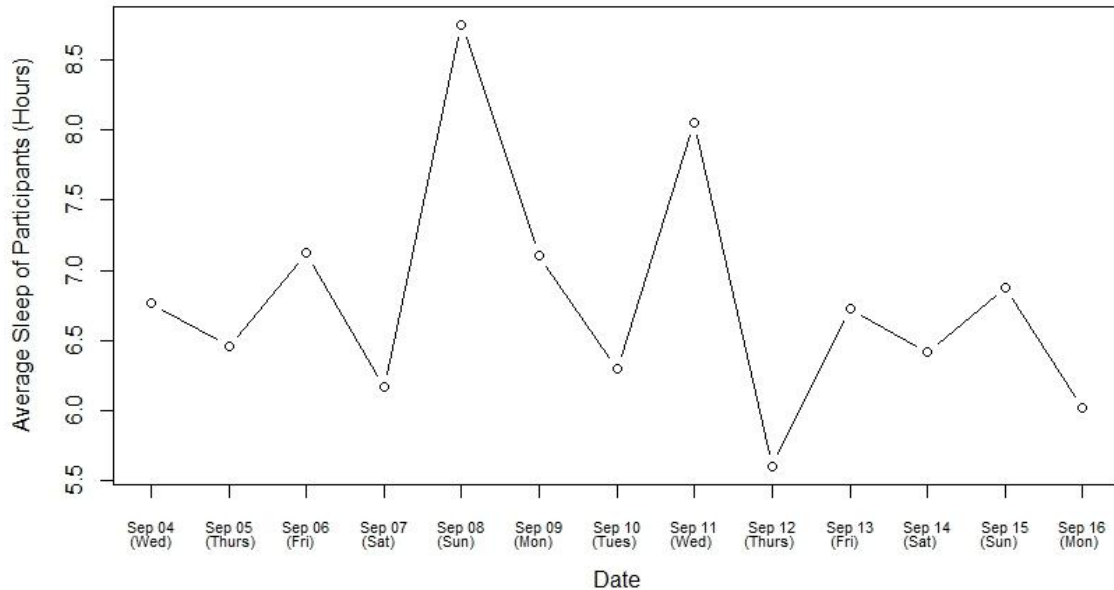
Figure 44.   Average day-to-day sleep of the nine participants from Period 2.

As shown in Figure 44, although on the first Sunday, 8 September, the average sleep of officers in Period 2 was over an hour greater than any other day, there was not a day-of-the-week effect as there was in Period 1. Based on a Kruskal-Wallis Rank Sum Test (α = 0.05) there was not enough evidence to conclude that participant daily sleep was affected by the day of the week (p-value = 0.11). As there was a day-of-the-week effect in Period 1, the lack of a day-of-the-week effect for Period 2 suggests two possible issues: (1) officers were not routinely provided the opportunity to sleep more on Sundays (or any other day of the week); and (2) the need for recuperative sleep among officers was less; thus, even if provided the opportunity to sleep more, they did not feel the need to do so.

c.   Period 3

Period 3 consisted of only enlisted sailors from the Deck Department. Seven crewmembers participated in Period 3. During Period 3, the ship operated in the Red Sea in order to support U.S. national interests in the Middle East. The sailors stood watch either on the bridge or belowdecks and, as discussed in Chapter IV, Section B, used a three-section 5ON/10OFF watch schedule.

The day-to-day sleep of each participant was investigated. A plot similar to that shown for Participant 31, in Figure 45, was generated for each participant. As compared to the participants of Periods 1 and 2, the day-to-day sleep of the participants in Period 3 appears to be similar to that of sailors from Period 1; however, additional insight was gained by investigating the variance of participants' daily sleep.
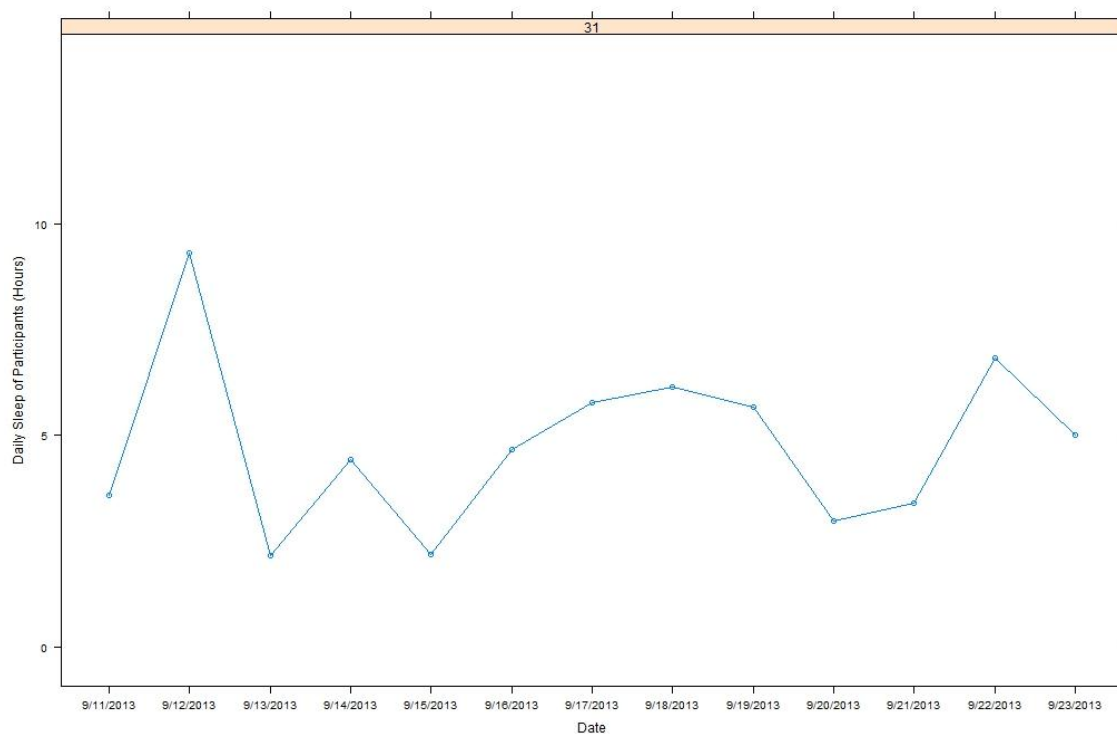
Figure 45.   Day-to-day sleep of Participant 31.

As shown in Figure 46, while the variability of some participants' day-to-day sleep was small, others were relatively large. The participants were all Seaman Boatswain's Mates and below, thus sailors of Period 3 were the most homogeneous group out of the three periods with regard to age, rank, military experience, and daily schedule. Unlike the participants of Period 1, however, when comparing the day-to-day sleep of the seven participants from Period 3, according to the Fligner-Killeen Test of Homogeneity of Variances (α = 0.05), the variance of participants' day-to-day sleep was statistically different (p-value = 0.01). Thus, even though the daily schedules of each of the sailors in Period 3 were similar, the consistency of their day-to-day sleep was different. This finding suggests that even though sailors may be provided the same amount of time to sleep each day, the consistency of their day-to-day sleep may still be different. Every person is different with regard to sleep and this should be taken into account by supervisors in operational units.
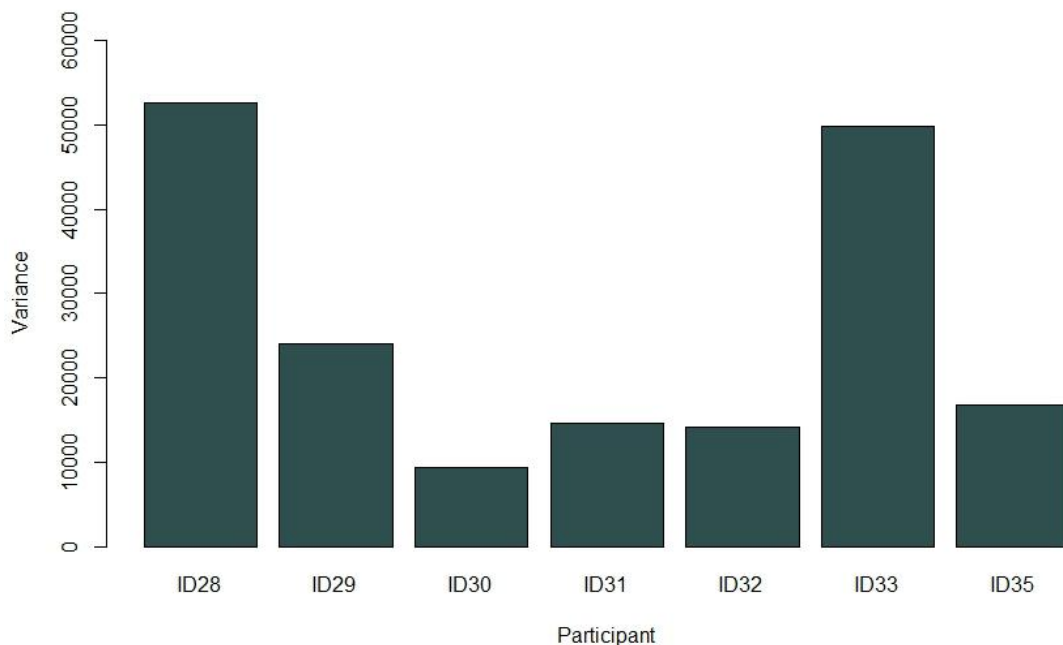
Figure 46.   Variance of day-to-day sleep for participants from Period 3.

Figure 47 displays average daily sleep as a function of the variance of each participant's day-to-day sleep. The red lowess fit shows that average daily sleep as a function of the variance of day-to-day sleep varied widely. However, this can most likely be attributed to the small number of data points. Based on a Spearman Rank Correlation Test (α = 0.05), with ρ = 0.21 and p-value = 0.70, there was not enough evidence to conclude that a correlation existed between average daily sleep and sleep consistency. Sleep consistency had little effect on the actual amount of sleep that sailors received in Period 3.
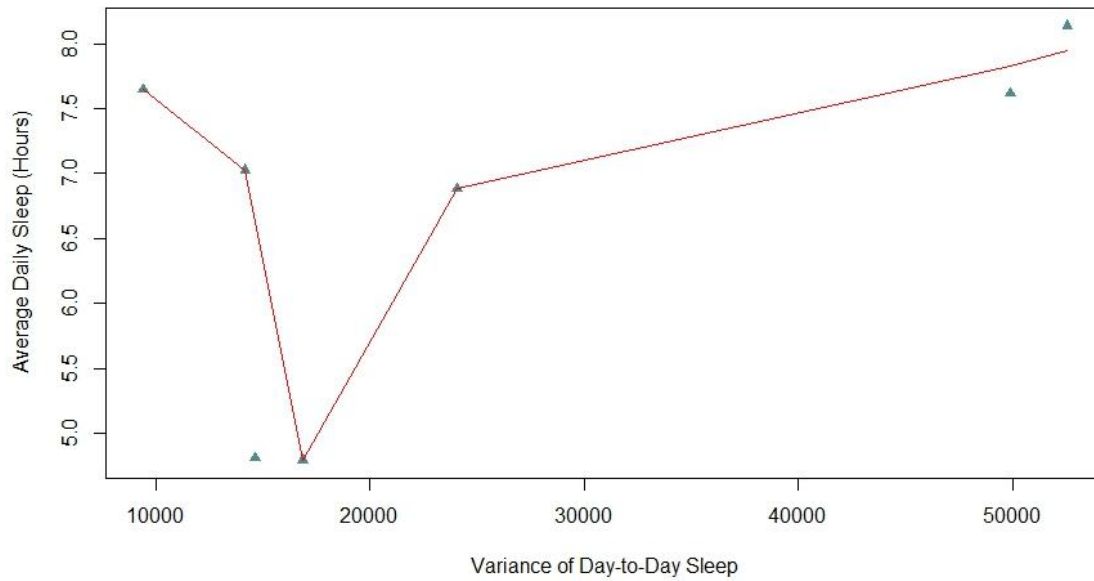
Figure 47.   Scatter plot of average daily sleep as a function of participant day-to-day sleep variance for Period 3.

Figure 48 displays the average day-to-day sleep of the participants of Period 3. Each point represents the average sleep of the seven participants for that day. Although the average sleep of the participants in Period 3 changed substantially day-to-day, it appears to do so less than that for the participants in Periods 2 and 3. Based on Mood Tests for Equality of Variance (α = 0.05) between Periods 1 and 3 and Periods 2 and 3, there is not enough evidence to

conclude that the consistency in participant sleep is different between the periods (p-value for Periods 1 and 3 is 0.34 and the p-value for Periods 2 and 3 is 0.84).
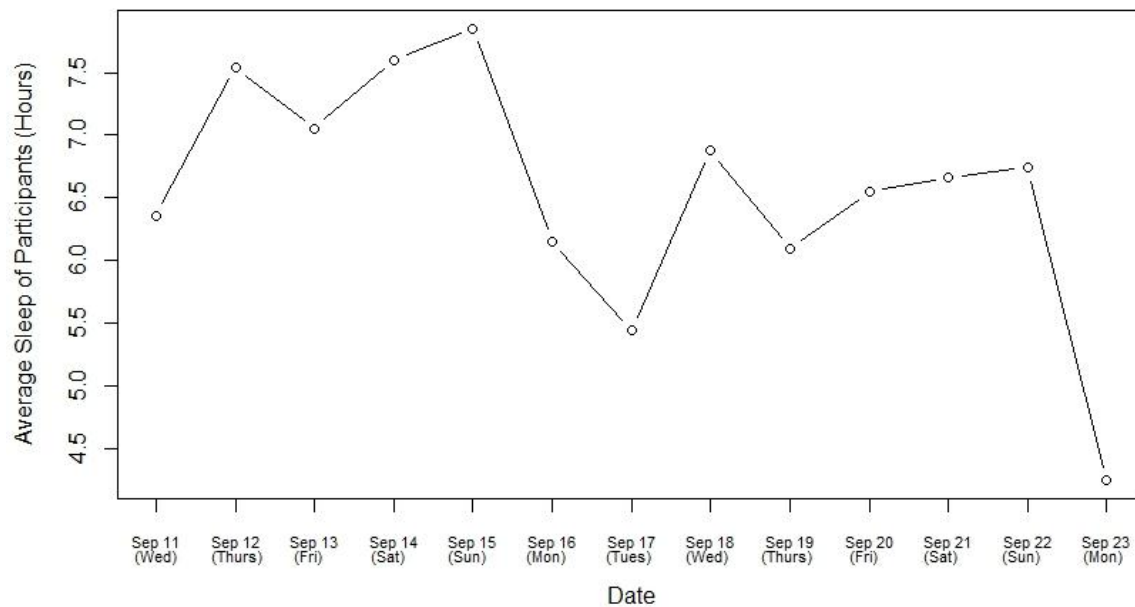
Figure 48.   Average day-to-day sleep of the seven participants from Period 3.

Although on the first Sunday, 14 September, the average sleep of the sailors in Period 3, as shown in Figure 48, was higher than all other days during the period, there was not a day-of-the-week effect as there was during Period 1. Based on a Kruskal-Wallis Rank Sum Test (α = 0.05), there was not enough evidence to conclude that participant daily sleep was affected by the day of the week (p-value = 0.54). Since there was a day-of-the-week effect in Period 1, the lack of a day-of-the-week effect for Period 3 suggests two issues: (1) the need for recuperative sleep among the sailors in the Deck Department was less; thus, even if provided the opportunity to sleep more, they did not feel the need to do so; and (2) sailors in the Deck Department were not provided with a day to recover from sleep debt, unlike sailors in the Reactor Department. Additional research is required to further investigate the differences between the departments and to explore reasons for potential differences.

D.   NAVY STANDARD WORKWEEK ANALYSIS

Participants were asked to complete daily sleep and activity logs indicating, for each 15-minute interval of the day, the NSWW category in which they were engaged. Both actigraphic sleep and self-reported sleep were included in the NSWW analysis. The data from the sleep and activity logs and the actigraphic sleep data were compared to the requirements described in CNO (2011) in order to determine if the NSWW accurately reflects sailors' work weeks on a deployed aircraft carrier. Due to incomplete sleep and activity logs and actigraphy data for some participants, only 26 participants were included in the NSWW analysis. Of these 26 participants, 13 were from the Reactor Department, 3 were from the Deck Department, and 10 were officers.

1.   Comparison of Self-Reported Activities and Actigraphic Sleep to the Navy Standard Workweek

Figure 49 displays the daily self-reported activities and actigraphic sleep of Participant 2, a Second Class Petty Officer Electronic's Technician (Nuclear) in the Reactor Department. During the study, Participant 2 stood Instrumentation Watch, a watch responsible for monitoring key reactor plant safety equipment, in the reactor plant spaces of Reactor Plant Number 1. In addition, Participant 2's collateral duty as "Paperwork Petty Officer" required him to prepare and maintain all reactor plant maintenance paperwork for Reactor Plant Number 1, a critical and time-intensive job. Participant 2's watch rotation was five hours on watch and 15 hours off watch. Figure 50 displays his activities in hours per week in order to provide a more direct comparison to the NSWW. Appendix G contains the self-reported activities and actigraphic sleep, as compared to the NSWW, of all 26 participants included in the NSWW analysis.
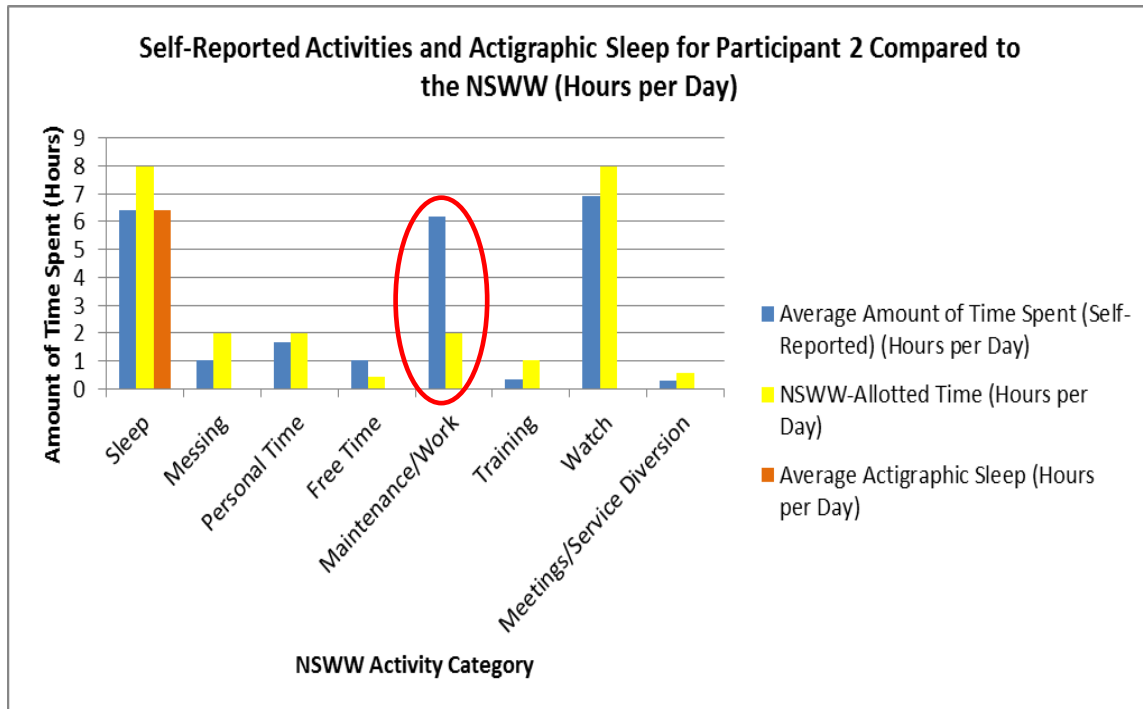
Figure 49.   Reported activities and actigraphic sleep of Participant 2 compared to the NSWW (hours per day).
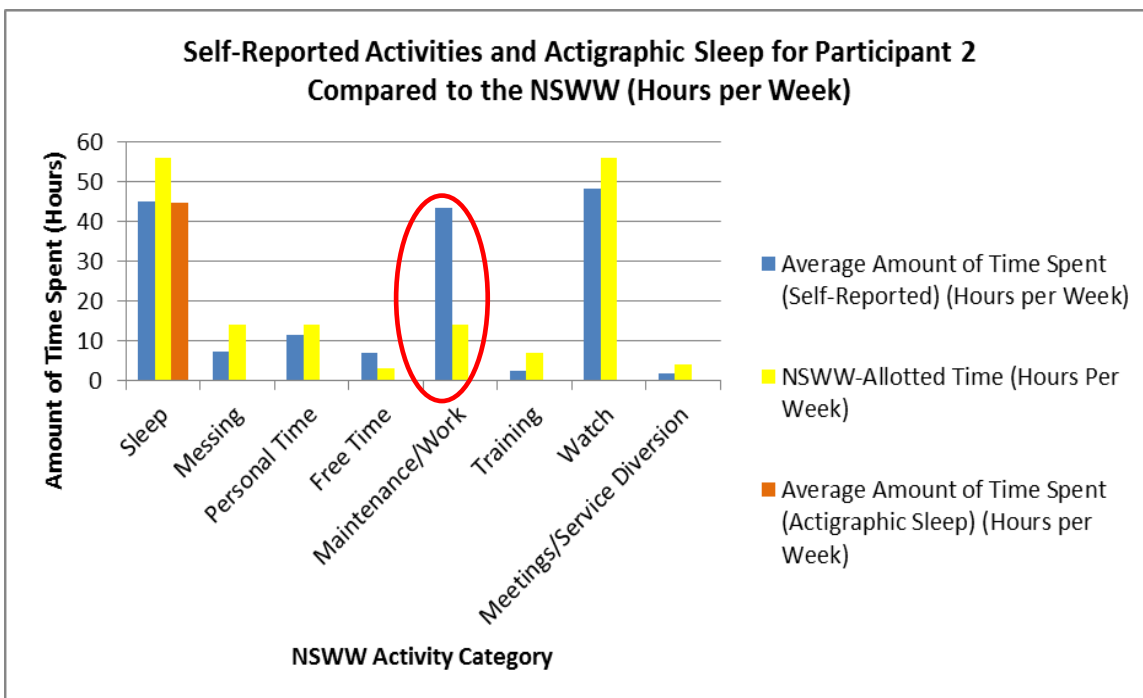
Figure 50.   Reported activities and actigraphic sleep of Participant 2 compared to the NSWW (hours per week).

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Only the categories of free time and maintenance/work exceeded the time allotted by the NSWW. Time spent in all other categories was less than that designated by the NSWW. This sailor spent a tremendous amount of time each day doing maintenance and work. Participant 2's collateral duty clearly dominated his daily schedule. Appendix H contains plots illustrating the differences between self-reported activities and actigraphic sleep and the NSWW-allotted time per category for each of the 26 participants.

Figure 51 displays the deviation from the NSWW for Participant 2, computed as $Deviation = \dfrac{SR_{ij} - AL_j}{AL_j}$, where SR_{ij} is the time spent by participant i in NSWW category j and AL_j is the allotted time of NSWW category j for $i = 1,\ldots, 26$ and $j = 1,\ldots, 8$. Clearly, the largest deviation was for the category of maintenance and work. This participant's collateral duty, although he was still just a Second Class Petty Officer, was demanding and time consuming. The NSWW does not take such collateral duties into account when determining the amount of time sailors should spend doing work each week. Appendix I contains plots illustrating the deviations between self-reported activities and actigraphic sleep and the NSWW-allotted time per category for each of the 26 participants.
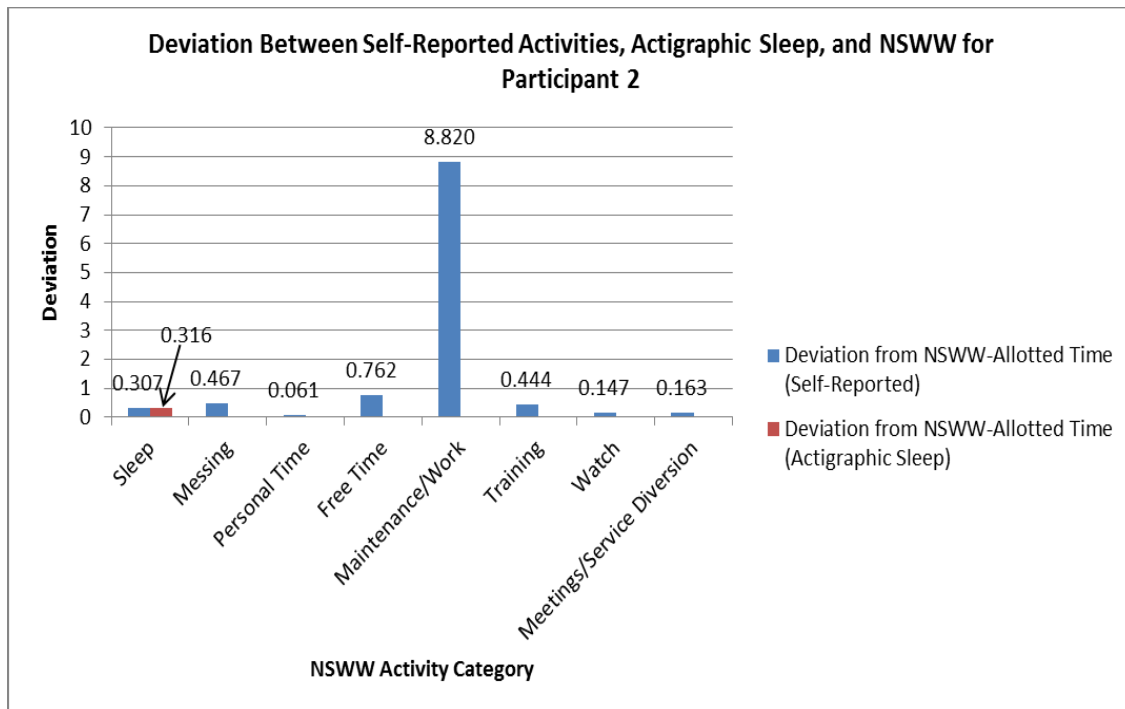
Figure 51.   Deviation between the self-reported sleep and actigraphic sleep and the NSWW-allotted time for Sailor 2.

Figure 52 displays the mean amount of time per day for self-reported activities and actigraphic sleep, compared to the allotted time designated by the NSWW for the 26 participants. On average, participants exceeded the requirements of the NSWW in the following categories: free time, maintenance/work, and meetings/service diversion. On the other hand, on average, participants fell below the requirements of the NSWW in the following categories: sleep, messing, personal time, training, and watch. Figure 53 displays the mean amount of time per week for self-reported activities and actigraphic sleep, compared to the allotted time designated by the NSWW.

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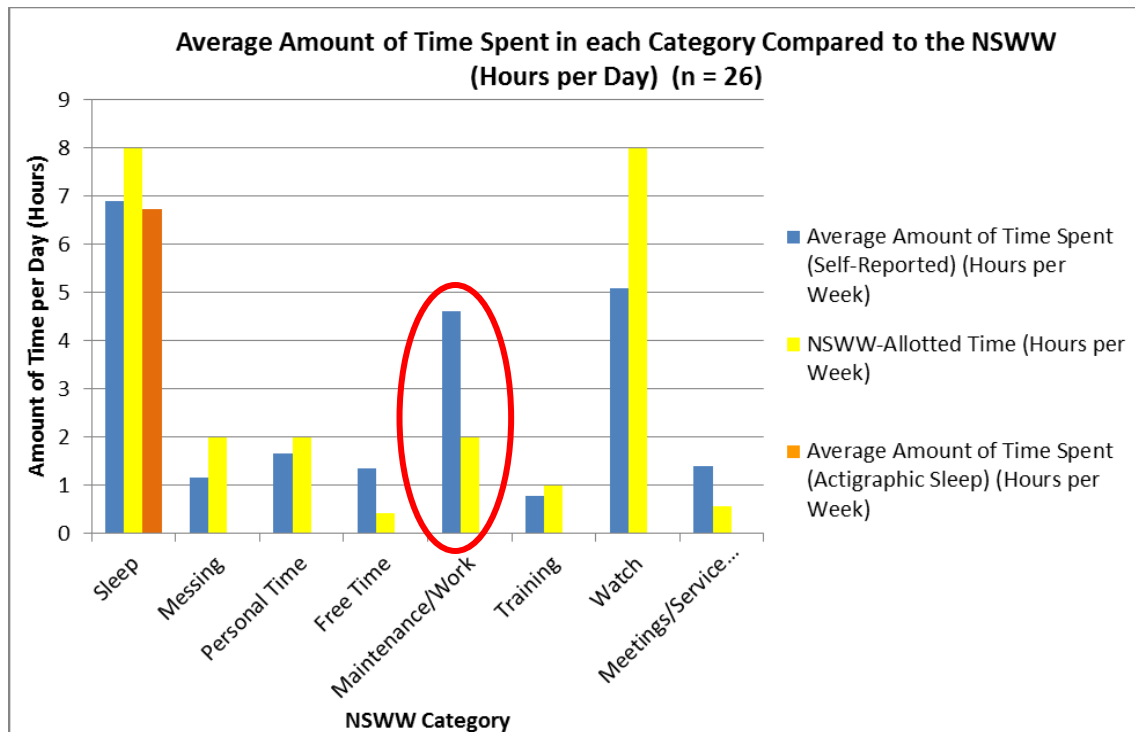
Figure 52.   Average amount of time spent in each category per day, compared to the NSWW for the 26 participants.
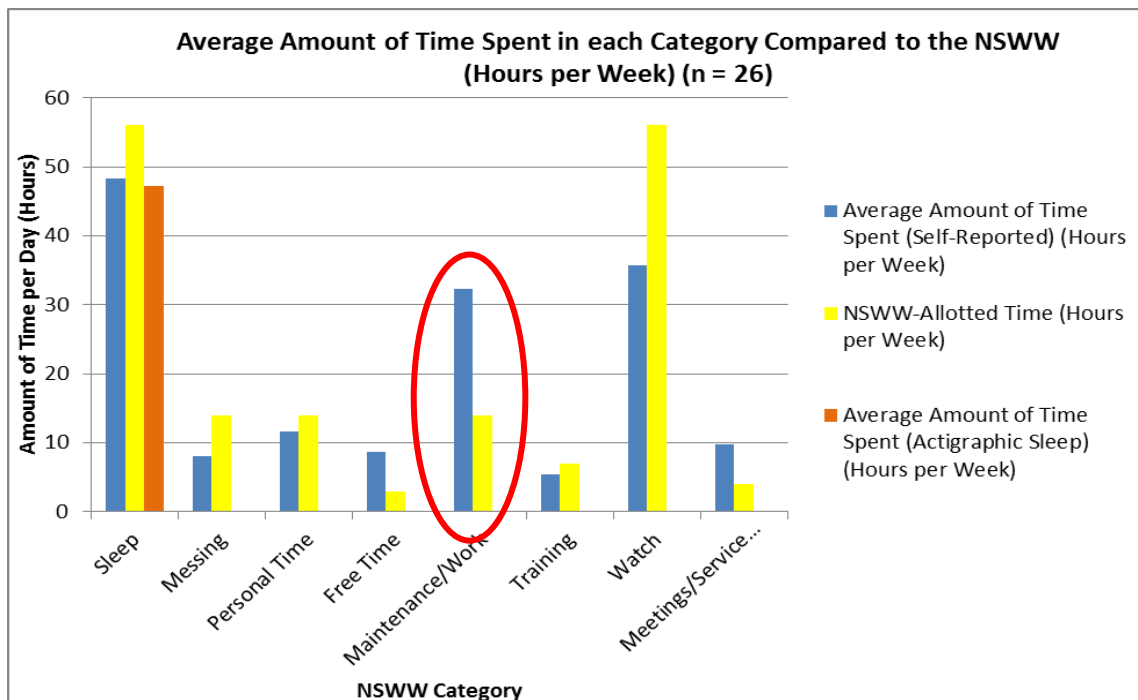
Figure 53.   Average amount of time spent in each category per week, compared to the NSWW for the 26 participants.

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Figure 54 illustrates the average deviation from the NSWW for the 26 participants. The greatest deviations were for the categories of free time, maintenance and/or work, and meetings/service diversion. The deviation for all other NSWW categories was less than 2.

Average Deviation from the NSWW for all Participants (n=26)
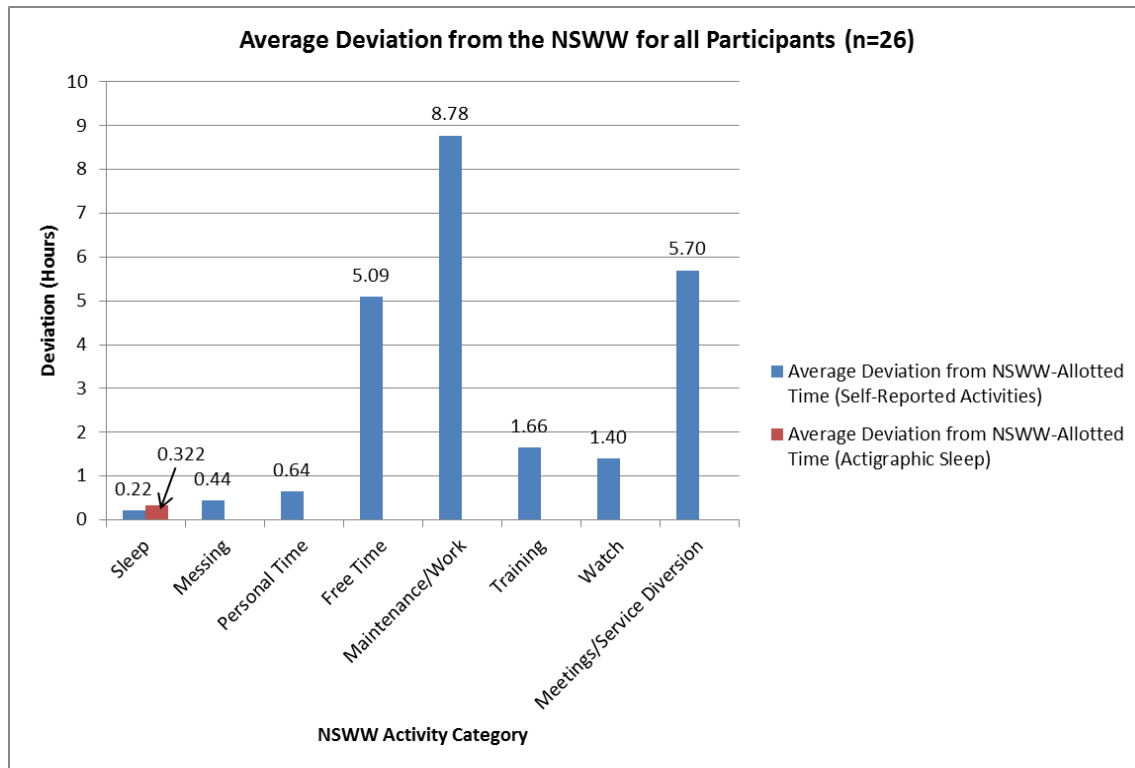
Figure 54.   Average deviation from each category of the NSWW for the 26 participants.

The relatively large deviations in the categories of free time, maintenance and work, and meetings and service diversion found in this sample of data highlight several key concerns with the NSWW. First, participants were doing more maintenance and/or work than called for by the NSWW. Second, participants were required to attend more meetings and unplanned events (service diversions) than called for by the NSWW. Third, participants, on average, were spending a significant amount of time engaged in free time. Yet, on average, participants were still not meeting the requirements of the NSWW with regard to sleep. Thus, a disconnect existed between watch scheduling,

maintenance/work requirements, and the time management of sailors. Perhaps the combination of a heavy workload, rotating watch schedules that are out of sync with the human circadian rhythm, and many unplanned events throughout the day made it difficult for sailors to sleep when time was available and ultimately hindered their ability to effectively manage their own time. Based on this analysis, the current NSWW cannot be considered an effective tool for determining manning onboard operational units because it does not accurately reflect the demands placed on sailors.

Figure 55 displays the average deviation by department for the NSWW. The deviations for sleep are based on actigraphic sleep. The greatest deviations for the departments were in the categories of maintenance/work, meetings/service diversion, and free time performed by officers, the Reactor Department, and the Deck Department, respectively. The Reactor Department, however, also deviated the second most in the maintenance/work and free time categories and deviated the most in the training category. In most other categories, the departments did not deviate by more than two hours from the NSWW. Based on Kruskal-Wallis Rank Sum Tests (α = 0.05) for each of the categories, however, there was no statistically significant difference between any of the departments for any of the categories (smallest p-value = 0.09).
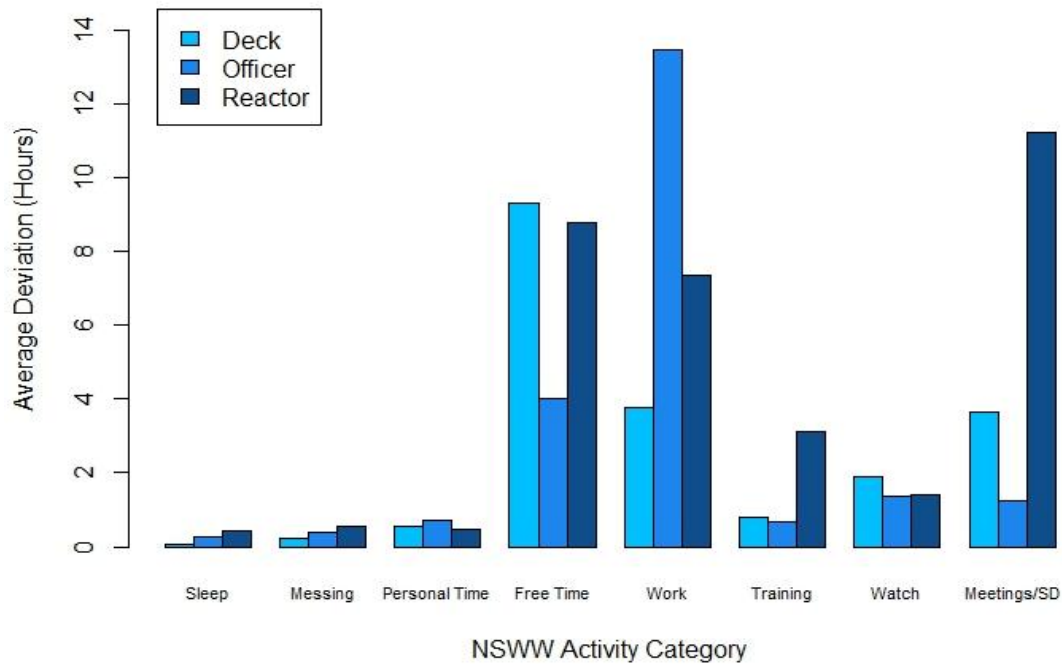
Figure 55.   Average deviation from the NSWW by department (n=26).

The participants from the Deck Department, consisting of sailors who were younger and more junior than participants from the other departments, reported the most free time. Additionally, participants from the Reactor Department, also tending to be much younger than officer participants, reported a substantial amount of free time. As shown in Figure 56, the amount of free time one reported tended to decrease as a function of age (ρ = –0.38). The red lowess smoother in Figure 56 and a Spearman Rank Correlation Test (α = 0.05), with a normally approximated p-value = 0.07, show a weak statistical negative correlation between age and the amount of free time one reported.
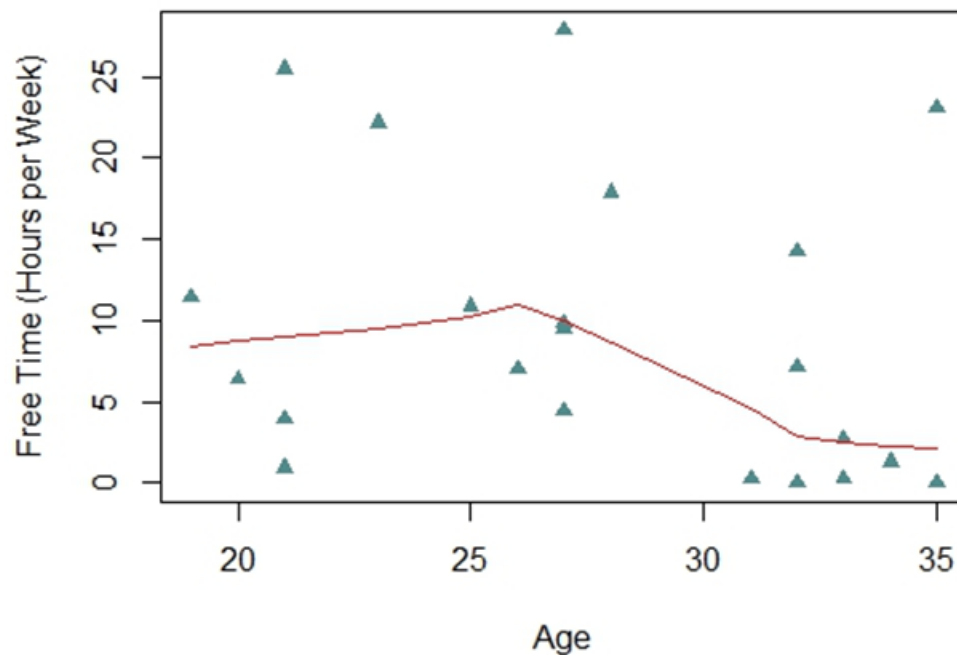
Figure 56.   Scatter plot of free time (hours per week) and age for the 26
             participants with a nonparametric lowess regression of free time as a
             function of age.

Table 16 presents the summary statistics for the amount of time that participants spent sleeping, completing maintenance and work, and the amount of time they spent in available and non-available time. Due to ties in the data, the confidence intervals for the medians of actigraphic sleep and maintenance and work were calculated by Wilcoxon Signed Rank Tests, using normal approximations and no continuity correction. The confidence intervals for the medians of available and non-available time were calculatedly exactly.

	Actigraphic Sleep	Maintenance/Work	Available	Non-Available
Mean	47.2	32.3	84.2	78.4
Median	47.0	30.7	83.0	79.7
Range	[31.6, 64.7]	[0, 87.23]	[46.8, 114.6]	[52.2, 102.5]
Standard Deviation	7.1	23.4	17.2	14.9
Skewness	0.3	0.4	–0.1	–0.3
Kurtosis	3.5	2.6	2.5	2.0
Confidence Interval (95%)	[44.6, 49.5]	[24.4, 44.2]	[77.0, 91.5]	[72.4, 85.7]

Table 16.   Summary statistics for the mean amount of time participants spent sleeping, completing maintenance and work, and in and available time and non-available time (hours per week) (n=26).

Figure 57 displays the amount of time that each sailor spent sleeping each week (based on actigraphic sleep), compared to the NSWW. The red and blue bars represent the sailors, while the NSWW requirement is displayed by the gold horizontal line. The mean weekly sleep is displayed by the green horizontal line. The left vertical axis displays the number of hours each sailor spent sleeping per week. The sailors that received less sleep than the NSWW allotment are represented with red bars, while those sailors that met or exceeded the NSWW allotment are represented with blue bars. The purple line with black diamonds depicts the cumulative percentage of actigraphic sleep as shown on the right vertical axis. Eighty-one percent of the total time slept by all 26 participants is contributed by sailors that slept 56 hours or less per week.
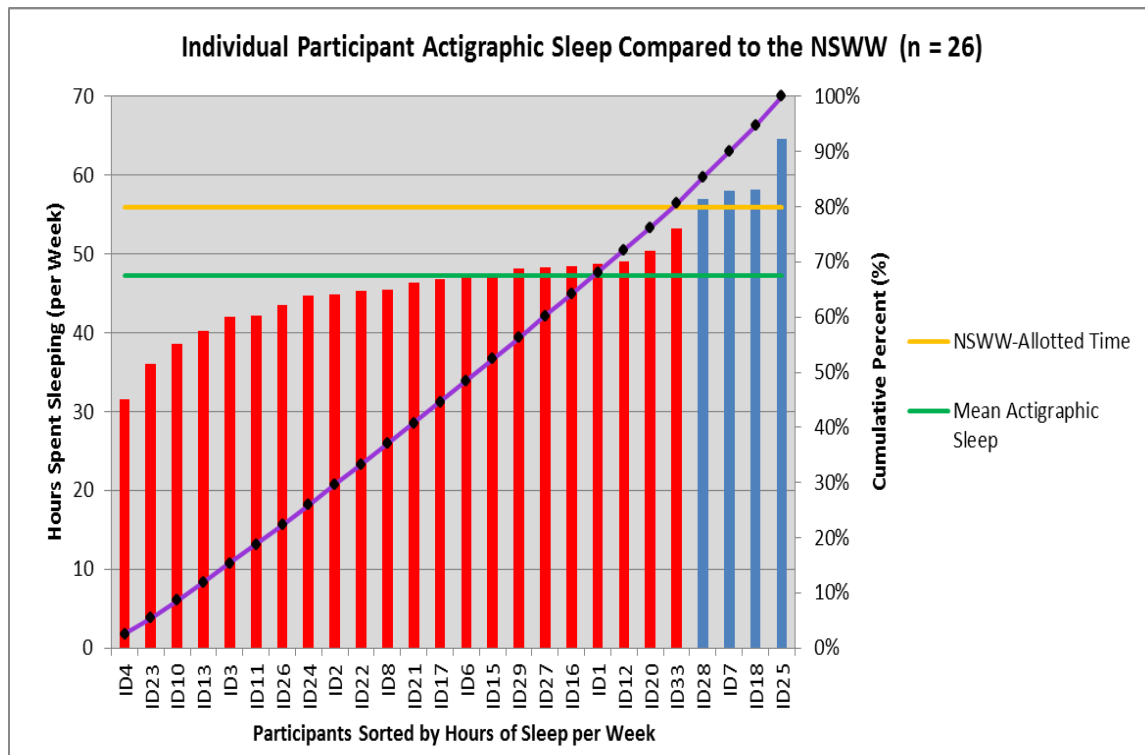
Figure 57.   Cumulative percentage of actigraphic sleep and individual sailor
actigraphic sleep, compared to the NSWW (hours per week).

Based on a one-tailed Wilcoxon Signed Rank Test (α = 0.05), the median
of actigraphic sleep was significantly less than the NSWW-allotted time (normally
approximated p-value = 3.8e–06). These results demonstrate that sailors tended
to sleep less per week than allocated in the NSWW.

Figure 58 depicts the time that each participant spent doing maintenance
and work, compared to the NSWW. The plot in Figure 58 is designed in the same
manner as the one in Figure 57. Only 3% of the total time that participants spent
doing maintenance and work was contributed by sailors that did less than 14
hours per week, as designated in the NSWW. Thus, participants in the study, as
a whole, worked much more than called for by the NSWW. Appendix J contains
graphs similar to Figure 57 and Figure 58 for all other categories of the NSWW.
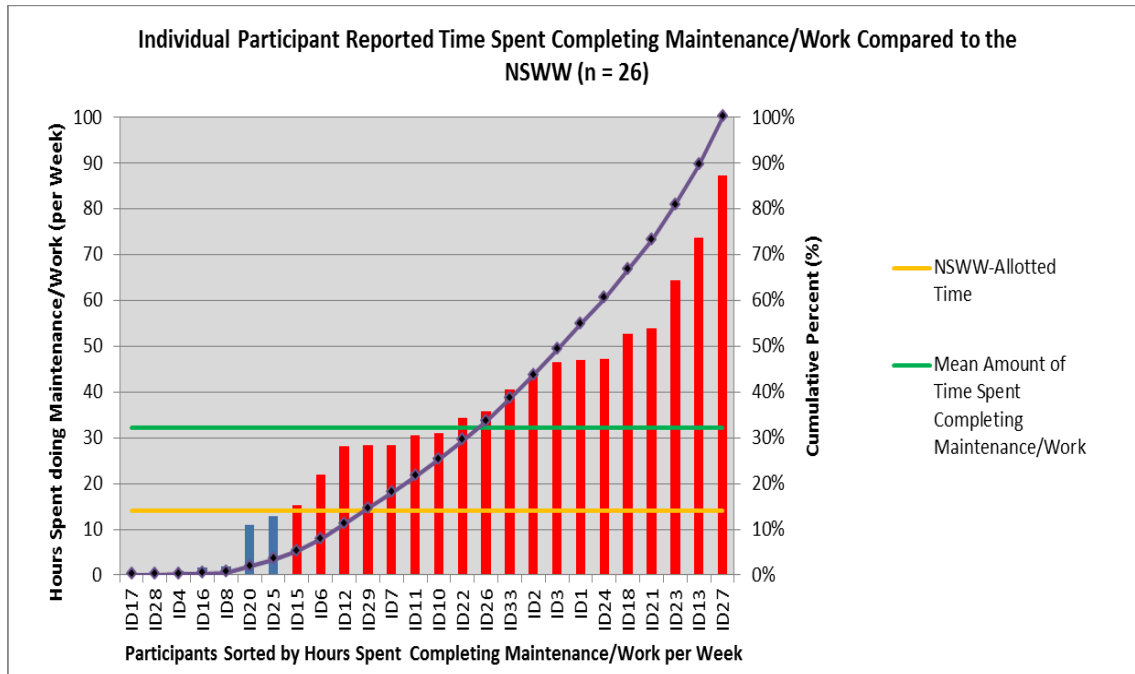
Figure 58.   Cumulative percentage of reported time spent doing maintenance and/or work and individual sailor time spent doing maintenance and/or work, compared to the NSWW.

Based on a one-tailed Wilcoxon Signed Rank Test (α = 0.05), the median of maintenance and work was significantly greater than the NSWW-allotted time of 14 hours (normally approximated p-value = 2.9e–4). These results demonstrate that sailors tended to work more per week than called for by the NSWW.

Next, the amount of time spent in available time and non-available time was analyzed and compared to the requirements of the NSWW. In order to make the analysis more accurate, actigraphic sleep was used in place of self-reported sleep. As actigraphic sleep differs from self-reported sleep, any difference between the two was appropriately added (or subtracted) from available time in order to ensure that each participant's time was accurately accounted for. Also, due to short watch removal times and/or periods of time in which a participant's time could not be accurately accounted for, the sum of all participants' available and non-available time did not necessarily add up to 168 hours. Even

considering these caveats, this analysis still provided insight into the amount of time each week that sailors were required to work versus the time they were allowed to sleep, eat, and take care of personal items, compared to the NSWW.

Figure 59 depicts the amount of time that each participant spent in available time, compared to the NSWW. The blue and red bars represent individual sailors and the left vertical axis is the amount of time spent in available time. The gold horizontal line represents the 81 hours of allotted available time designated by the NSWW. The green curve with black diamonds depicts the cumulative percentage of available time, as shown on the right vertical axis. Forty-two percent of the total available time of the 26 participants was contributed by sailors that spent 81 hours or less per week in available time. In other words, the majority of the participants' time, as a whole, was spent in available time.
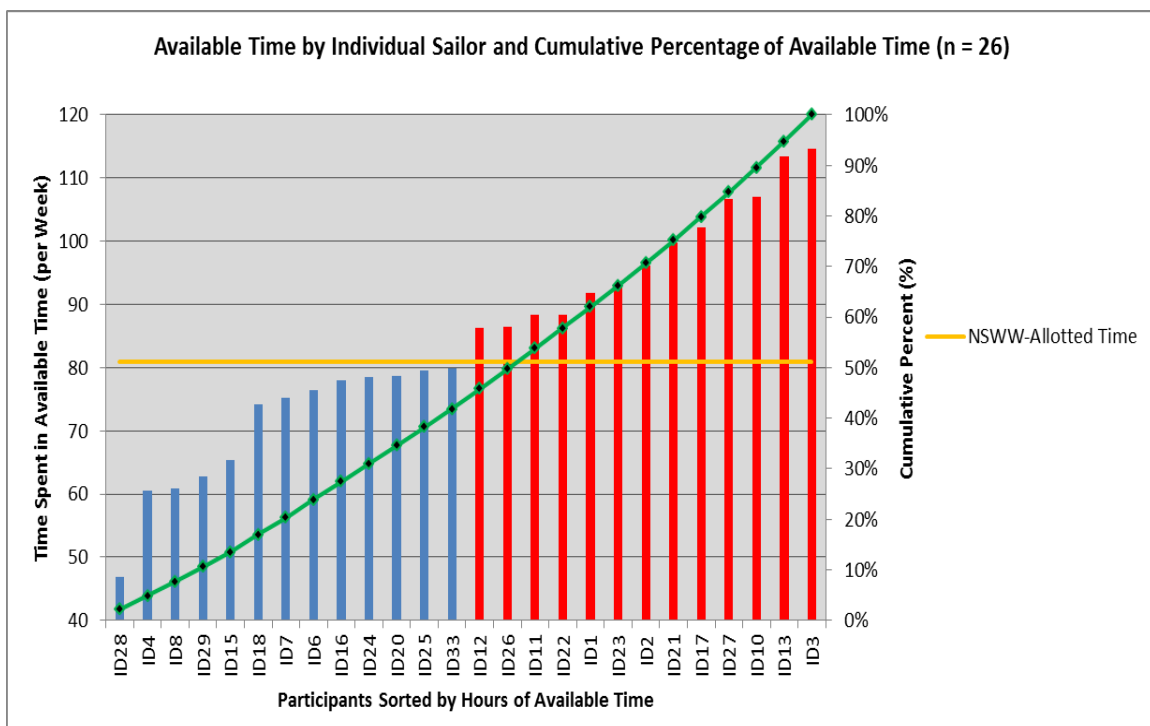
Figure 59.   Cumulative percentage of available time and the amount time that each participant spent in available time, compared to the NSWW.

Based on a one-tailed Wilcoxon Signed Rank Test (α = 0.05), there was not enough evidence to conclude that the median of participant available time is significantly greater than the NSWW-allotted time (p-value = 0.18). These results demonstrate that while some participants spent much more time in available time than called for by the NSWW, others spent less time and there was large variability in the available time data.

Figure 60 depicts the time that each participant spent in non-available time, compared to the NSWW. The plot is designed the same as the one in Figure 59. Fifty-nine percent of the total non-available time of the 26 participants was contributed by sailors that spent 87 hours or less per week in non-available time.
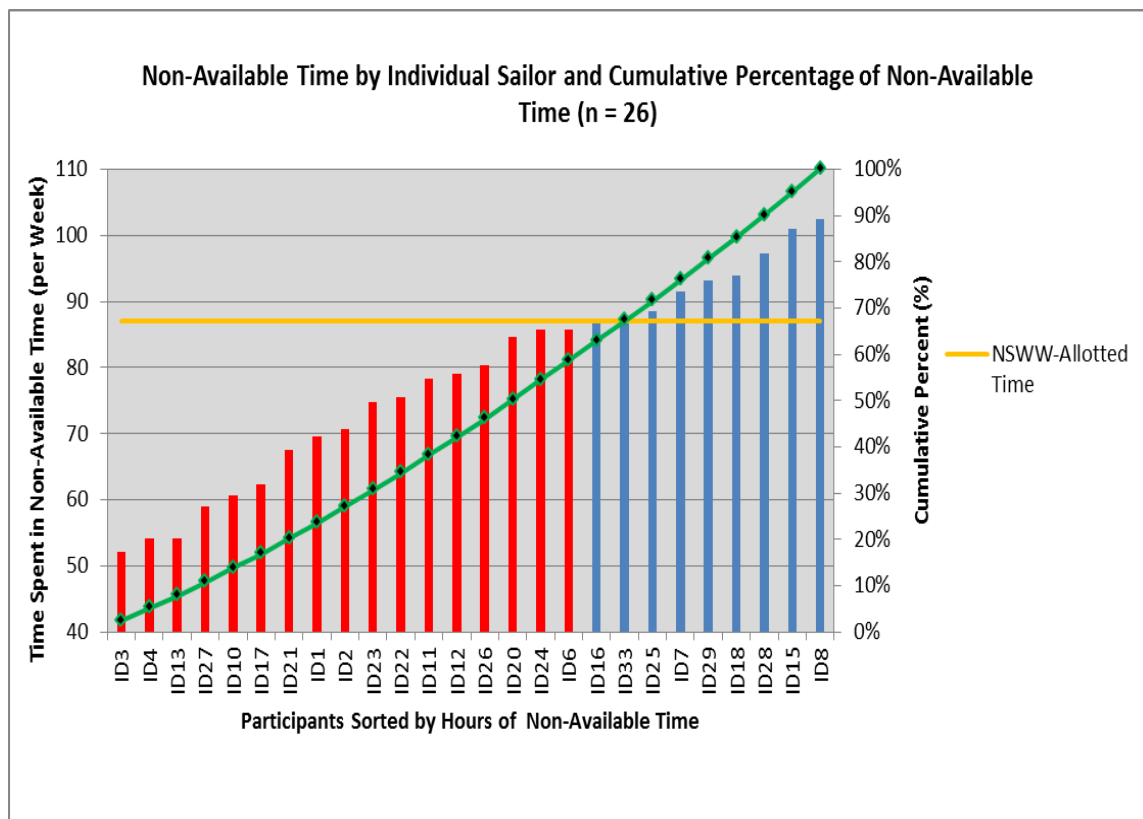
Figure 60.   Cumulative percentage of non-available time and the amount time that each participant spent in non-available time, compared to the NSWW.

Based on a one-tailed Wilcoxon Signed Rank Test (α = 0.05), the median was statistically significantly less than the NSWW-allotted time (p-value = 0.006). Participants did not spend as much time in non-available time as called for by the NSWW.

E.   COMPARISON OF ACTIGRAPHIC SLEEP AND SELF-REPORTED SLEEP

In order to gain additional insight into any possible differences between self-reported and actigraphic sleep, a statistical comparison of the two sets of data was conducted. Due to incomplete sleep and activity logs and/or actigraphy data for some participants, only 26 participants were included in this analysis. Thirteen participants were from the Reactor Department, three were from the Deck Department, and 10 were officers.

1.   Distributional Analysis

Figure 61 displays a histogram of average daily sleep based on the actigraphic data for the 26 participants. The data appears to be somewhat normally distributed. Based on the Lilliefors Normality Test (α = 0.05), there is not enough evidence to conclude that the data is not normally distributed (p-value = 0.07); however, due to the relatively small sample size and the heavy tails as shown in the Normal Q-Q plot in Figure 62 non-normality is more likely and normality was not assumed in the subsequent analyses.
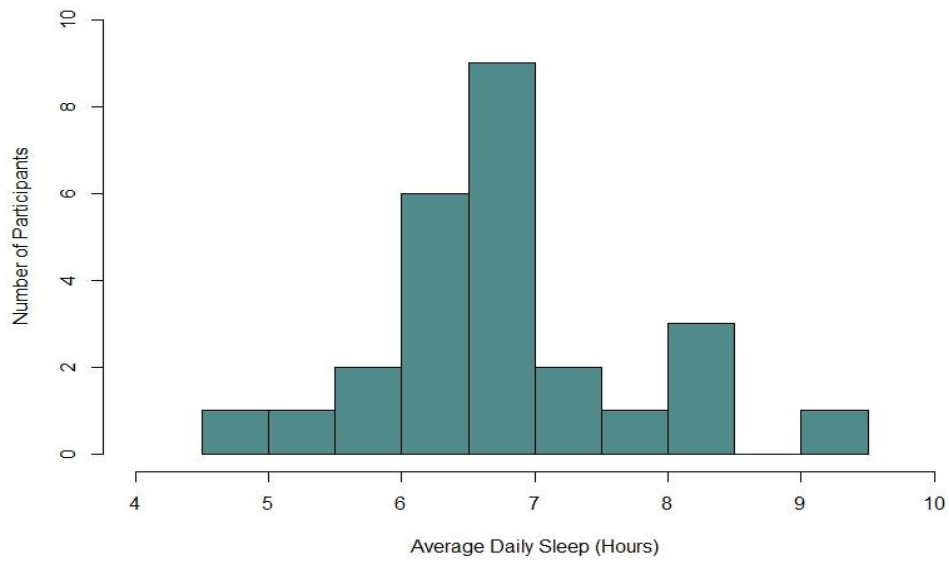
Figure 61.   Histogram of average daily sleep, based on actigraphic data of the 26 participants.
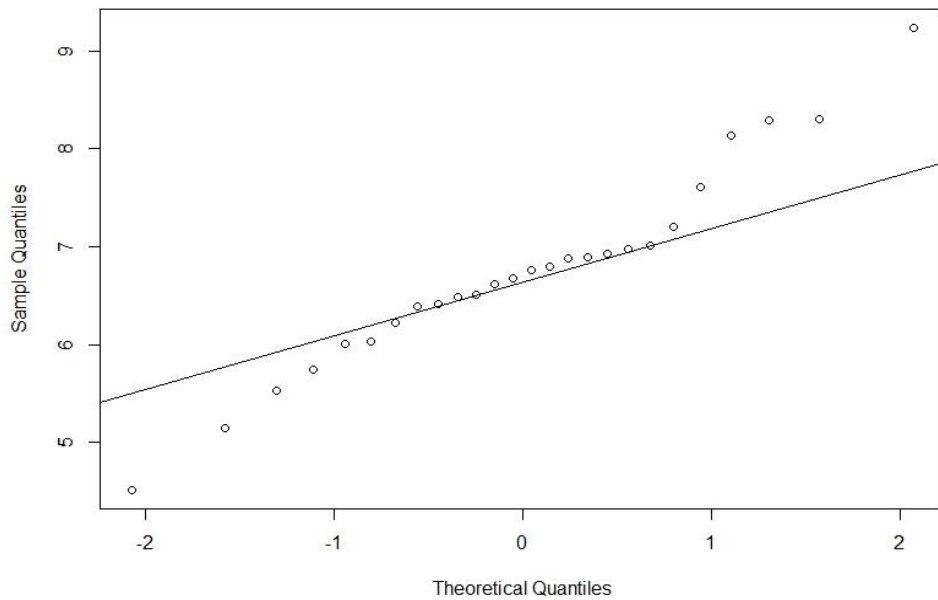
Figure 62.   Normal Q-Q plot of average daily sleep, based on actigraphic sleep for the 26 participants.

Similarly, as shown in Figure 63, the distribution of average daily sleep based on self-reported sleep appears to be normally distributed. However, based

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on the Lilliefors Normality Test (α = 0.05), there is enough evidence to conclude that the data is most likely not normally distributed (p-value = 0.05). Therefore, normality was not assumed in the subsequent analyses.
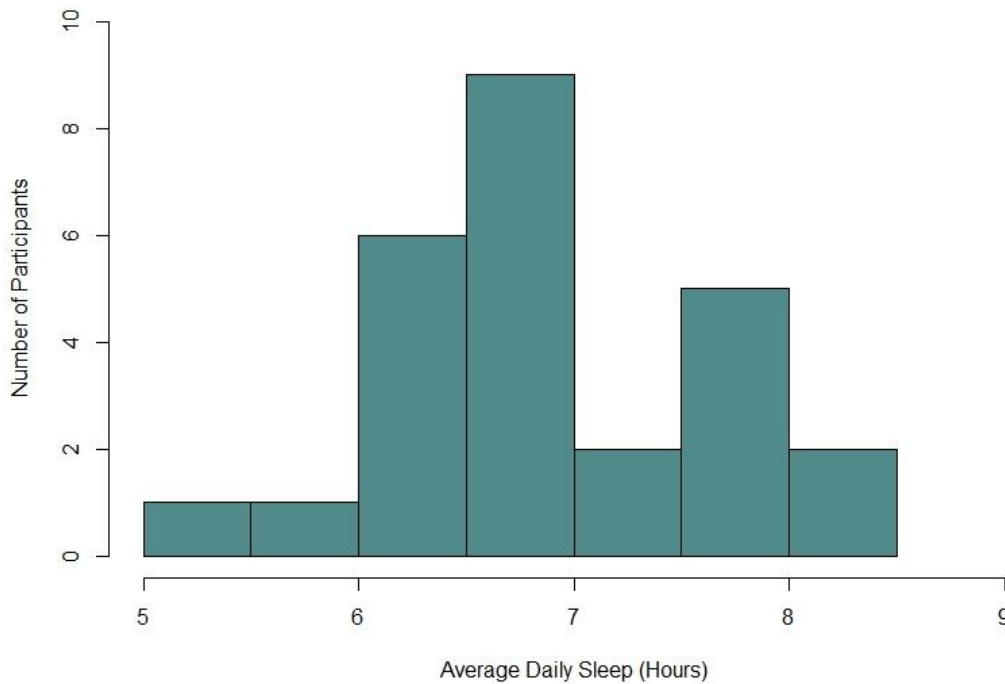
Figure 63.   Histogram of average daily sleep based on the self-reported sleep of the 26 participants.

The distributions of average daily sleep for the actigraphic data and self-reported sleep of the 26 participants appear to be relatively similar. Based on a Two-Sample Kolmogorov-Smirnov Test (α = 0.05), with the p-value determined through a 10,000-replication simulation, there was insufficient statistical evidence to conclude that the distribution of average daily sleep for actigraphic sleep and self-reported sleep were different (p-value = 0.93).

2.   Comparative Analysis

Although the distributions of actigraphic and self-reported sleep are similar, potential differences between the two samples were still possible. Figure

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64 displays the average daily actigraphic and self-reported sleep of individual participants, compared to the NSWW. The horizontal blue line represents the NSWW-allotted time of eight hours of sleep per day. The participants are sorted by hours of actigraphic sleep (orange bars), while the blue bars represent hours of self-reported sleep. The green and purple horizontal lines depict the mean of self-reported and actigraphic sleep per week, respectively. It is apparent in Figure 64 that the means of both actigraphic and self-reported sleep are over one hour less than the NSWW-allotted time of eight hours.
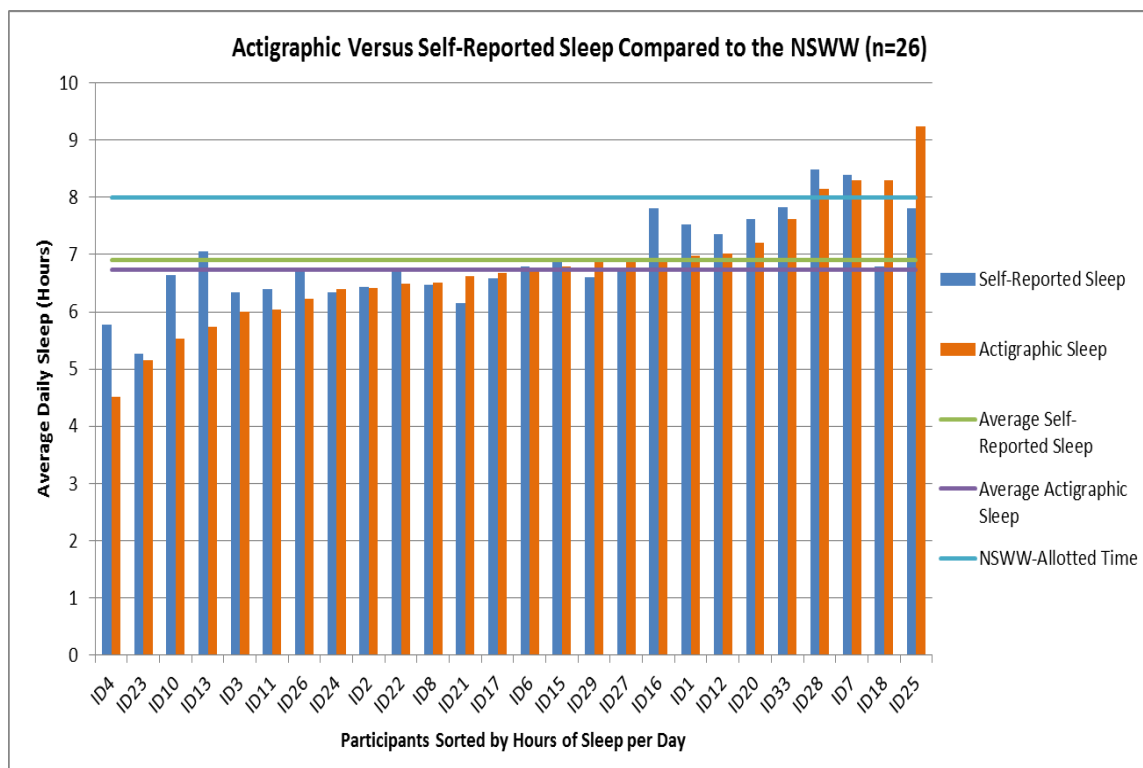
Figure 64.   Actigraphic sleep versus self-reported sleep, compared to the NSWW-allotted time.

Figure 65 displays a histogram of the absolute differences between actigraphic and self-reported sleep for the 26 participants. The summary statistics for average daily actigraphic and self-reported sleep and the absolute difference between the two forms of sleep data are displayed in Table 17. The confidence interval provided for actigraphic sleep was calculated exactly by a

Wilcoxon Signed Rank Test. Due to ties in the data, the confidence interval for self-reported sleep was normally approximated as calculated by a Wilcoxon Signed Rank Test.
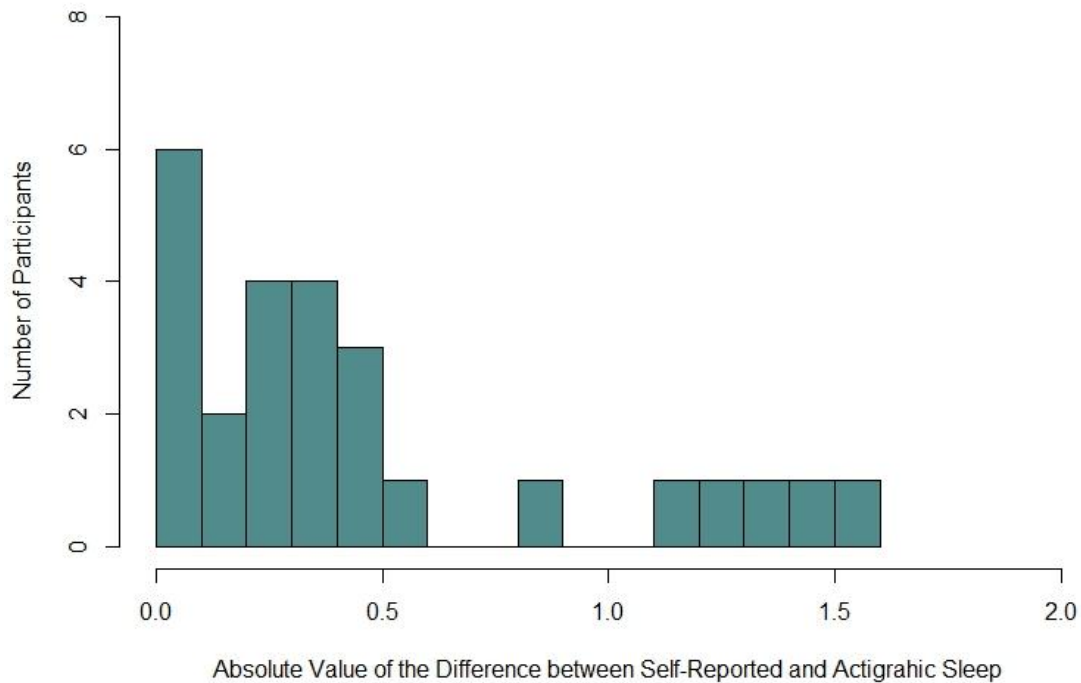
Figure 65.   Histogram of the absolute differences between actigraphic and self-reported sleep for the 26 participants.

	Actigraphic Sleep	Self-Reported Sleep	Absolute Difference
Mean	6.9	6.7	0.5
Median	6.7	6.7	0.3
Range	[4.5, 9.2]	[5.3, 8.5]	[.02, 1.5]
Standard Deviation	0.8	1.0	0.5
Skewness	0.3	0.3	1.1
Kurtosis	2.8	3.5	2.9
Confidence Interval (95%)	[6.6, 7.2]	[6.4, 7.1]	[.2, .7]

Table 17.   Summary statistics for average daily actigraphic sleep, average daily self-reported sleep, and the absolute difference between actigraphic and self-reported sleep (hours per day).

Based on a one-tailed Wilcoxon Signed Rank Test, with the actigraphic and self-reported sleep of each participant paired (α = 0.05), actigraphic sleep

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was significantly less than self-reported sleep (p-value = 0.03). Additionally, the 95% confidence interval for the median of the difference between actigraphic and self-reported sleep, as determined by a Wilcoxon Signed Rank Test, was [–.4, .01]. Perhaps this finding suggests that participants perceived that they were sleeping more than they were in actuality. This finding also highlights the cognitive degradation associated with chronic sleep debt and the common phenomenon of sleep-deprived individuals having trouble assessing how much sleep they are receiving over a given period of time.

Figure 66 is a scatter plot of average daily actigraphic sleep, as a function of average self-reported sleep. The red line is a linear regression, which shows a strong positive correlation (ρ = 0.78) between self-reported and actigraphic sleep as does the green lowess smoother. Furthermore, 59% of the variation in actigraphic sleep was accounted for by self-reported sleep.
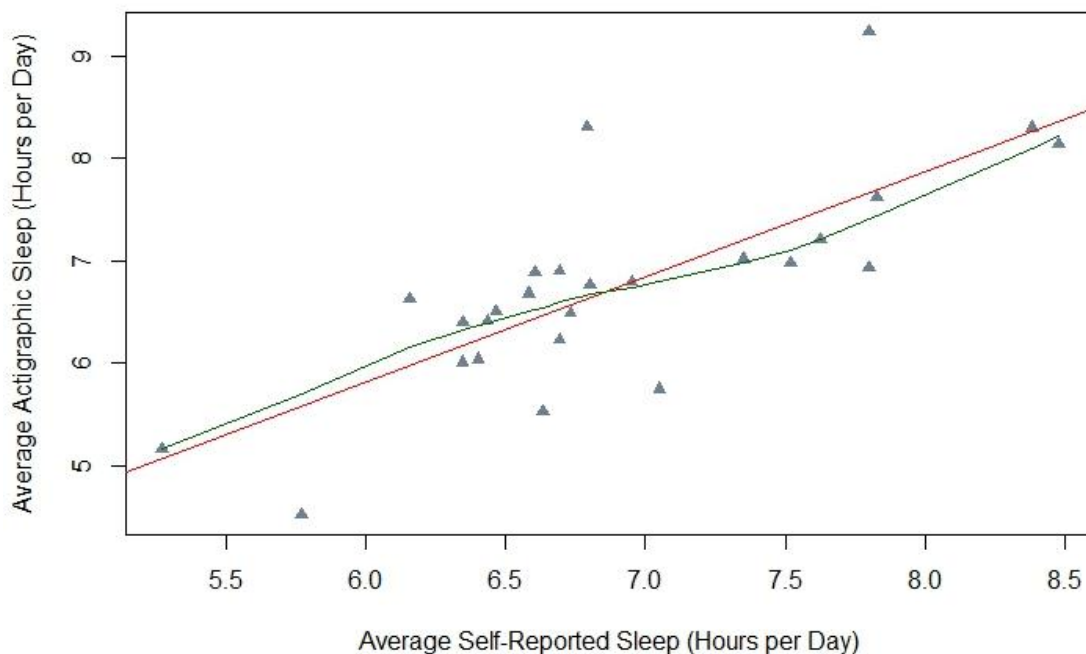
Figure 66.   Scatter plot of average daily actigraphic sleep and average daily self-reported sleep with a linear regression (red) and a nonparametric lowess regression (green).

To determine the effects of different levels of sleep on one's ability to accurately self-report sleep, the participants were broken into three groups based on their average daily sleep as determined by actigraphy: participants sleeping less than six hours, between six and eight hours, and more than eight hours.

Figure 67 graphically displays the difference between self-reported and actigraphic sleep for the three groups. Clearly, the three groups differed from one another. Of note, the group of participants that received greater than eight hours of sleep tended to under-report their sleep, those participants that received less than six hours of sleep tended to over-report their sleep, and those participants receiving between six and eight hours of sleep most accurately reported their sleep. Based on a Kruskal-Wallis Rank Sum Test (α = 0.05), there was a statistically significant difference between the three different groups with regard to the difference between self-reported and actigraphic sleep (p-value = 0.03). In other words, the amount of sleep that a participant received affected the accuracy with which they self-reported sleep. In particular, those participants receiving less than an average of six hours of sleep per day tended to over-report the amount of sleep they were getting.
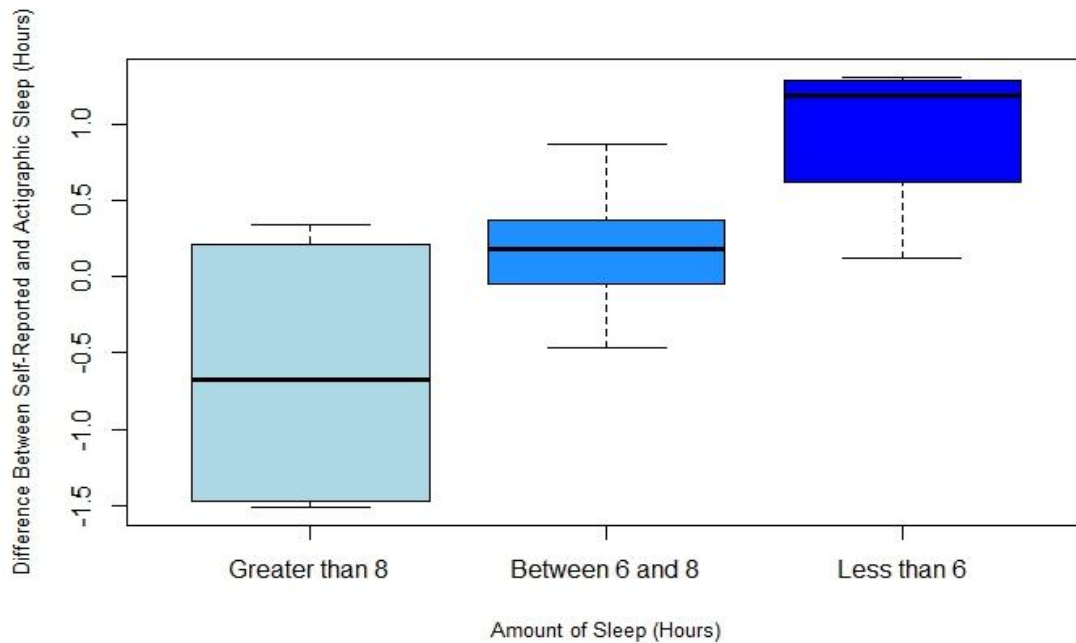
Figure 67.   Box plot of the difference between self-reported and actigraphic sleep, based on the amount of sleep that participants received.

Next, a multiple comparison of the different sleep groups in regards to the absolute difference between actigraphic and self-reported sleep was conducted. Based on a pairwise Multiple Comparison Wilcoxon Rank Sum Test using Holm's p-value adjustment procedure (family-wide α =0.05), there was only weak statistical evidence to conclude that a statistically significant difference exists between any of the groups (p-value = 0.08). As displayed in Table 18, the strongest case for a difference between groups existed between those participants that received less than six hours of sleep and those that received between six and eight. This suggests that participants that experienced severe sleep-debt (less than six hours of sleep) tended to be more likely to over-report their sleep while those that experienced a moderate amount to little sleep-debt (between six and eight hours of sleep) tended to report their sleep more accurately.

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	Between 6 and 8	Less than 6
Less than 6	0.08	-
More than 8	0.23	0.11

Table 18.   Table of pairwise p-values for the three different ranges of average daily sleep, using the Multiple Comparison Wilcoxon Rank Sum Test, using Holm's p-value adjustment.

These results suggest four issues: (1) sleep deprivation detrimentally affected participants' ability to accurately assess their own sleep; (2) individuals receiving less sleep tend to over-report the amount of sleep that they are actually getting; (3) individuals sleeping more tend to under-report the amount of sleep that they are actually getting; and (4) self-reported sleep cannot be the sole source of sleep data relied on by researchers, due to its inaccuracy as a result of human error.

The findings presented in the comparison of self-reported and actigraphic sleep differ from the results of a prior study of self-reported and actigraphic sleep conducted on a group of 669 young adults in Chicago (Lauderdale, Knutson, Yan, & Rathouz, 2009). First, the Chicago study found only a 0.45 correlation between actigraphic and self-reported sleep. Second, it only found that 20% of the variation in actigraphic sleep was accounted for by self-reported sleep. Third, the Chicago study found that at its actigraphic mean of six hours, self-reported sleep differed the most, whereas, in this thesis, self-reported sleep differed the most at daily sleep levels less than six hours.

F.   SAFTE-FAST ANALYSIS

SAFTE-FAST was used to determine and analyze on-watch predicted effectiveness and the proportion of the total on-watch time spent below the criterion level of 77.5. The criterion level of 77.5 is equivalent to a BAC of approximately .05 and is the level at which the United States Air Force (USAF) applies countermeasures to improve performance. In operational environments, predicted effectiveness levels below this criterion require additional investigation. Due to incomplete actigraphic and self-reported sleep and activity logs, only 25

participants were included in the SAFTE-FAST analysis. Twelve participants were from the Reactor Department, three were from the Deck Department, and 10 were officers. Both on-watch predicted effectiveness and the proportion of time spent below criterion were analyzed with respect to age, gender, commissioning status, department, watchstation location, and ESS and CSM scores. The FAST plots for all participants are in Appendix K.

1.   On-Watch Predicted Effectiveness

The overall distribution of mean on-watch predicted effectiveness for the 25 participants, as shown in Figure 68, appears to be somewhat normally distributed. The Shapiro-Wilk Test for normality (α = 0.05) confirms that the data is most likely normally distributed (p-value = 0.25); however, normality will not be assumed due to the relatively small sample size.
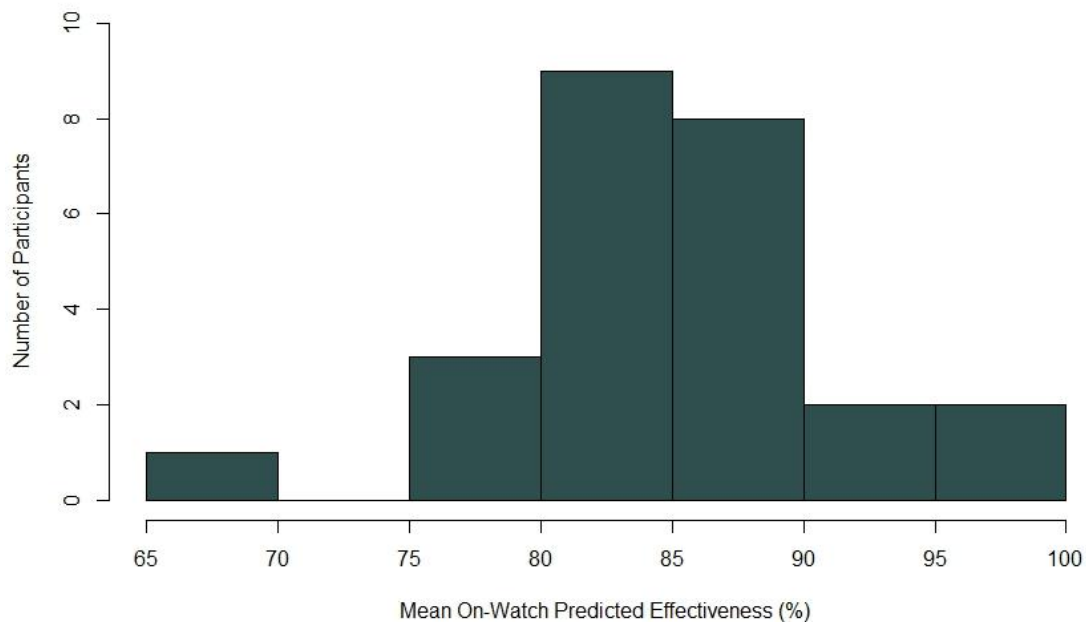
Figure 68.   Distribution of the mean on-watch predicted effectiveness for the 26 participants.

The summary statistics for average on-watch predicted effectiveness are presented in Table 19. All confidence intervals provided in the table of summary statistics are for the median of average on-watch predicted effectiveness, as calculated exactly by Wilcoxon Signed Rank Tests. For the Deck Department, the Reactor Department, and officers, 75%, 95%, and 95% confidence intervals are provided, respectively. The confidence interval for the Deck Department is only 75%, due to the limited number of Deck Department participants included in the SAFTE-FAST analysis (n = 3).

	Mean	Median	Range	Std Dev	Skewness	Kurtosis	Confidence Interval
All Participants	84.6	84.9	[67.4, 95.9]	6.4	−0.59	3.7	[82.4, 87.0]
Male	84.1	84.5	[67.4, 95.9]	7.0	−0.50	3.3	[80.4, 93.5]
Female	86.3	85.2	[80.4, 93.5]	4.4	0.50	2.6	[80.9, 87.4]
Enlisted	82.7	84.4	[67.4, 88.8]	5.3	−1.70	5.8	[80.3, 85.3]
Officer	87.5	88.3	[75.9, 95.9]	7.1	−0.60	2.2	[82.1, 92.1]
Reactor	81.9	83.3	[67.4, 88.8]	5.6	−1.50	4.8	[78.1, 85.0]
Deck	86.2	85.3	[85.1, 88.3]	1.8	0.69	1.5	[85.1, 88.3]
Belowdecks	83.2	84.4	[67.4, 90.4]	7.1	−0.30	2.1	[80.5, 86.3]
Topside	86.8	86.8	[75.9, 95.9]	5.7	−1.50	5.1	[80.7, 91.8]
Intermediate Type	85.0	85.1	[67.4, 95.9]	6.3	−0.85	4.7	[82.9, 87.8]
Morning Type	83.0	84.7	[75.9, 93.5]	7.4	0.32	1.8	[75.9, 93.5]
Elevated ESS	82.5	82.9	[75.3, 93.5]	5.3	0.33	2.9	[79.1, 85.1]
Normal ESS	86.3	87.5	[67.4, 95.9]	6.9	−1.30	5.4	[84.2, 89.9]

Table 19.   Summary statistics for average on-watch predicted effectiveness (n = 25).

Table 20 presents the two-tailed p-value and the name of the statistical test used for each of the tests of statistical significance conducted with regard to average on-watch predicted effectiveness for the different variables of interest. All p-values provided in this table are calculated exactly.

	p-value (2-tailed)	Type of Test	Statistically Significant?
Gender	0.56	Wilcoxon Rank Sum	No
Commissioning Status	0.04	Wilcoxon Rank Sum	Yes
Department	0.04	Kruskal-Wallis Rank Sum	Yes
Watchstation Location	0.13	Wilcoxon Rank Sum	No
ESS	0.04	Wilcoxon Rank Sum	Yes
CSM	0.58	Wilcoxon Rank Sum	No

Table 20.   P-value results and the name of the statistical test used for determining statistical significance (α = 0.05) for average on-watch predicted effectiveness for the variables of interest.

Several past studies have found that moderate levels of fatigue produce performance decrements equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working, and operating heavy machinery (Dawson & Reid, 1997; Lamond & Dawson, 1999). One participant often stood watch while significantly impaired. Thus, the minimum average on-watch predicted effectiveness is important to note, because 67.4 corresponds to a BAC of approximately 0.08, the legal limit for operating a motor vehicle. Additionally, a level of 65 is equivalent to 40 hours of sustained wakefulness. This participant experienced several periods of extreme sleep debt and, as a result, his on-watch performance suffered. Additionally, 4 of the 25 (16%) participants' mean on-watch predicted effectiveness was less than the criterion level of 77.5. Of these four, two participants were from the Reactor Department and two were officers.

a.   Commissioning Status

The summary statistics for average on-watch predicted effectiveness for enlisted sailors and officers are displayed in Table 19. The boxplot in Figure 69 displays additional information about the average on-watch predicted effectiveness according to commissioning status. As shown in Table 20, the difference in on-watch predicted effectiveness between officers and enlisted sailors was statistically significant. Officers' on-watch predicted effectiveness tended to be greater than that of enlisted sailors.
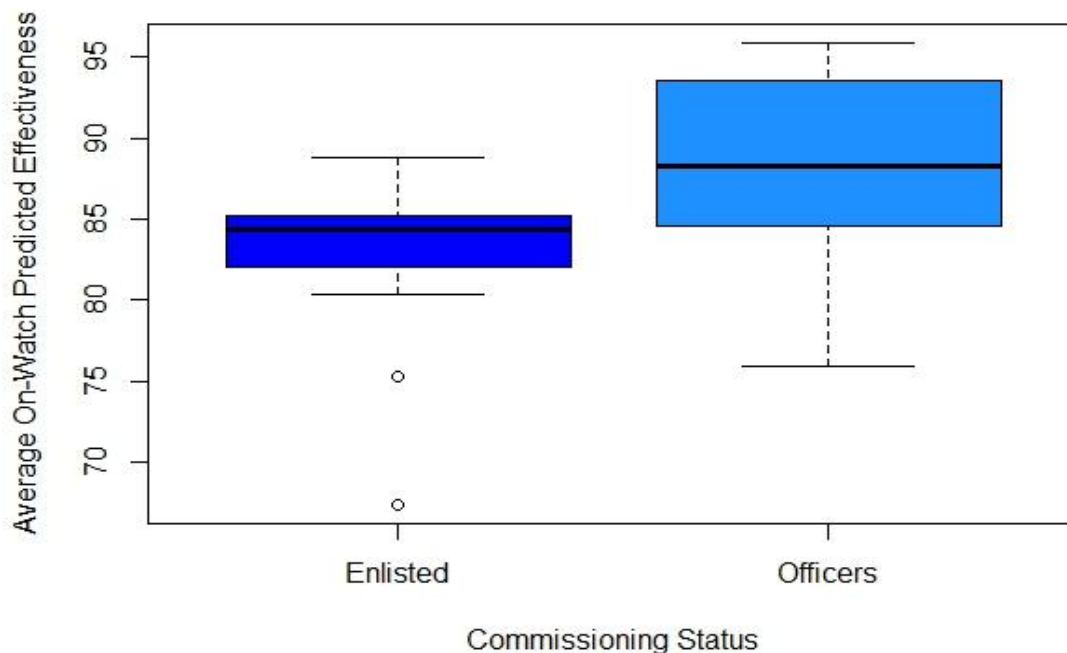
Figure 69. Box plot of average on-watch predicted effectiveness, delineated by commissioning status.

One of the most likely contributing factors was the difference in watch rotations between officers and enlisted sailors. Most officers stood 4ON/20OFF, while enlisted sailors stood either 5ON/15OFF or 5ON/10OFF. Having shorter watches with more time off provided more time to not only sleep, but also to get additional work completed. Thus, even though the NSWW analysis shows that officers spent more time doing work than the other groups, they were provided more time to complete their work.

b.   Department

The summary statistics for average on-watch predicted effectiveness according to department are presented in Table 19. Figure 70 displays additional information about the average on-watch predicted effectiveness of the departments. As shown in Table 20, the difference in average on-watch predicted effectiveness between the three groups was statistically significant.
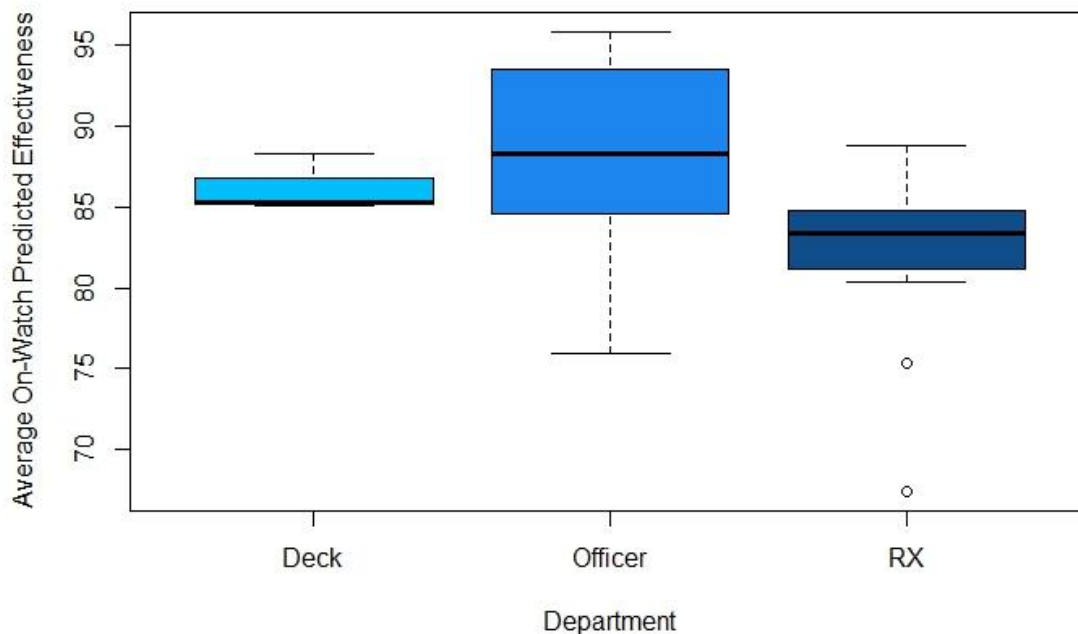
Figure 70.   Boxplot of average on-watch predicted effectiveness, delineated by department.

Next, a multiple comparison of the average on-watch predicted effectiveness of the different departments was conducted. Based on a pairwise Multiple Comparison Wilcoxon Rank Sum Test using Holm's p-value adjustment procedure (family-wide α = 0.05), there was only weak statistical evidence to conclude that a statistically significant difference existed between any of the groups (smallest p-value = 0.09). As displayed in Table 21, the strongest case for a difference between groups existed between the Reactor Department and the officers.

	Deck	Officers
Officers	0.47	-
Reactor	0.14	0.09

Table 21.   P-values of all pairwise comparisons for the average on-watch predicted effectiveness, according to department.

These finding suggest that officers tended to have a higher average on-watch predicted effectiveness; however, due to the weak evidence, additional research may need to be conducted to confirm this result. Furthermore, even though the Reactor Department utilized a four-section 5ON/15OFF watch rotation, compared to the three-section 5ON/10OFF watch rotation used by the Deck Department (considered the least favorable watch rotation), the participants from the Reactor Department tended to experience lower average on-watch predicted effectiveness levels and differed even more from the officers. Furthermore, the Reactor Department spent the most time in service diversions (responding to unplanned events such as emergencies) and training and the second most time performing maintenance and work. This result points to other factors besides watch rotation, such as the amount of time spent performing maintenance and/or work, responding to emergencies, or training, as elements affecting on-watch performance levels. Thus, all of these factors must be taken into account when developing watch rotations and operational schedules on warships.

c.   Epworth Sleepiness Scale

The summary statistics for average on-watch predicted effectiveness, according to ESS category, are displayed in Table 19. Figure 71 displays additional information about average on-watch predicted effectiveness according to ESS category. As shown in Table 20, the difference in average on-watch predicted effectiveness between ESS categories was statistically significant.

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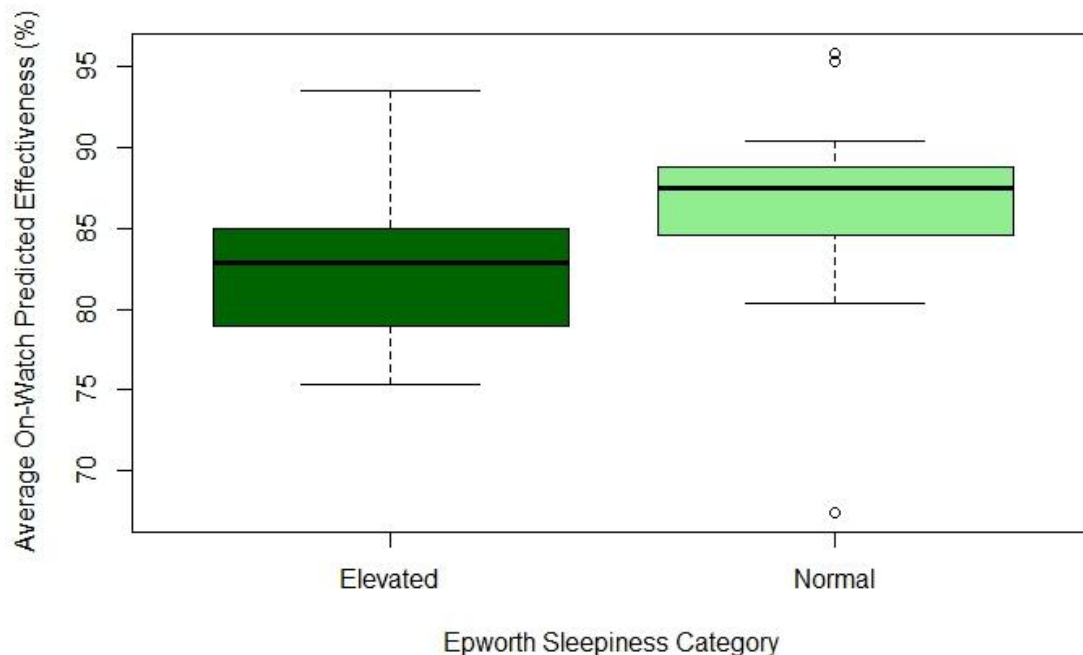
Figure 71.   Boxplot of average on-watch predicted effectiveness, delineated by ESS category.

These results suggest that the ESS could be a useful tool for not only diagnosing sleep-induced fatigue of personnel in operational environments, as discussed in Chapter IV, Section C.1.a, but also used as a means for identifying personnel who are potentially impaired due to sleep-related fatigue. By identifying potentially impaired personnel prior to certain critical events and time periods, such as watch, drills, or underway replenishments, operational commands will have the opportunity to administer fatigue countermeasures and/or amend watchbills and operational schedules to ensure that all personnel involved are at an adequate level of performance. Furthermore, the ESS is a quick, efficient, and cost-effective method for determining an individual's level of fatigue and potential impairment.

2.   Time Below Criterion

The proportion of on-watch time below the predicted effectiveness criterion level of 77.5 was determined and analyzed for each participant. Figure 72 displays the distribution of the proportion of on-watch time spent below

criterion. Based on the Lilliefors Test for normality (α = 0.05), there is strong statistical evidence that the data is not normally distributed (p-value = 0.001). Therefore, normality will not be assumed in subsequent analyses.
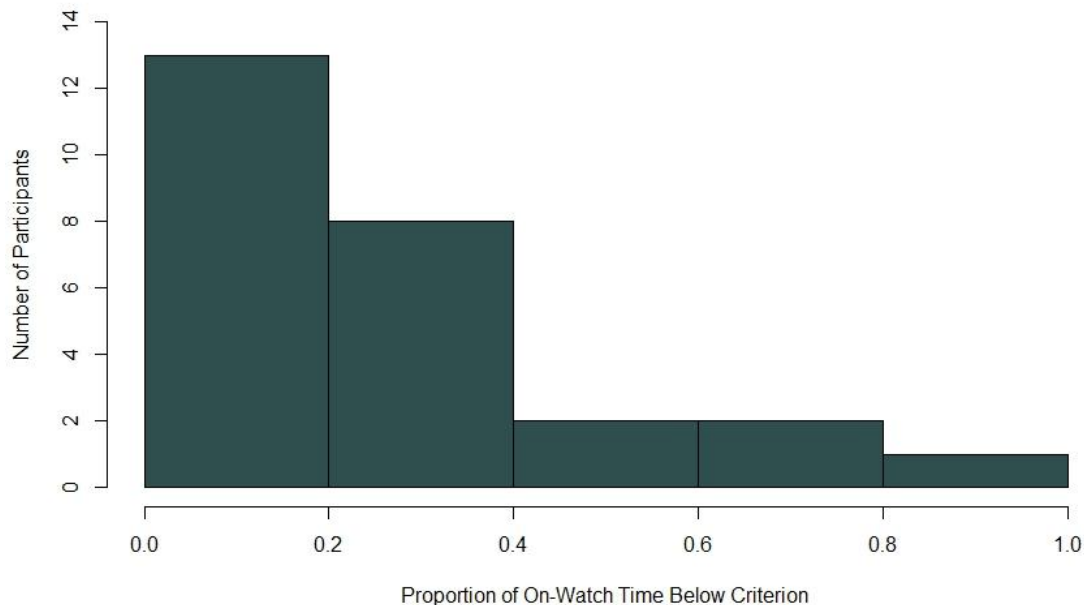
Figure 72.   Distribution of the proportion of on-watch time below criterion for the 25 participants.

The summary statistics for the proportion of on-watch time below criterion are displayed in Table 22. All confidence intervals provided in the table of summary statistics are for the median of average on-watch predicted effectiveness, as calculated exactly by Wilcoxon Signed Rank Tests. However, due to several officers never reaching the minimum predicted effectiveness level of 77.5 and, therefore, having a proportion of on-watch time below criterion equal to zero, they could not be used in the p-value calculation using the Wilcoxon Rank Sum Test. Thus, the number of observations for officers was limited, thereby reducing the power of the test and making the detection of any differences between the two groups more difficult. Additionally, the reduced number of usable observations for officers only allowed for an 80% confidence

interval to be calculated for the median of the proportion of on-watch time below criterion. For the Deck Department and Reactor Department, 75% and 95% confidence intervals are provided, respectively.

	Mean	Median	Range	Std Dev	Skewness	Kurtosis	Confidence Interval
All Participants	0.22	0.19	[0.0, 1.0]	0.23	1.70	6.4	[.18, .35]
Male	0.25	0.18	[0.0, 1.0]	0.27	1.30	4.0	[.17, .47]
Female	0.19	0.21	[0.0, .34]	0.11	−0.34	2.5	[.17, .28]
Enlisted	0.29	0.21	[.05, 1.0]	0.24	1.80	5.7	[.17, .41]
Officer	0.15	0.00	[0.0, .62]	0.23	1.20	2.9	[.15, .62]
Reactor	0.29	0.21	[.05, 1.0]	0.25	2.01	6.5	[.15, .41]
Deck	0.19	0.20	[.13, .23]	0.05	−0.54	1.5	[.13, .23]
Belowdecks	0.25	0.19	[0.0, 1.0]	0.24	2.20	7.6	[.15, .34]
Topside	0.18	0.10	[0.0, .62]	0.22	0.93	2.6	[.22, .47]
Intermediate Type	0.21	0.18	[0.0, 1.0]	0.23	2.20	8.6	[.17, .33]
Morning Type	0.28	0.23	[0.0, .62]	0.27	0.26	1.5	[.05, .62]
Elevated ESS	0.29	0.23	[0.0, .62]	0.18	0.44	2.6	[.20, .43]
Normal ESS	0.17	0.11	[0.0, 1.0]	0.27	2.50	8.5	[.10, .60]

Table 22.   Summary statistics for the proportion of on-watch time spent below criterion.

Table 23 presents the two-tailed p-value and the name of the statistical test used for each of the tests of statistical significance conducted, with regard to the proportion of on-watch time spent below criterion for the variables of interest. All p-values provided in this table are calculated exactly.

	p-value (2-tailed)	Type of Test	Statistically Significant?
Gender	0.95	Wilcoxon Rank Sum	No
Commissioning Status	0.08	Wilcoxon Rank Sum	No
Department	0.18	Kruskal-Wallis Rank Sum	No
Watchstation Location	0.4	Wilcoxon Rank Sum	No
ESS	0.03	Wilcoxon Rank Sum	Yes
CSM	0.54	Wilcoxon Rank Sum	No

Table 23.   P-value results and the name of the statistical test used for determining statistical significance, with regard to the proportion of on-watch time spent below criterion for the variables of interest.

a. Epworth Sleepiness Scale

The summary statistics for the proportion of on-watch time below criterion for participants with elevated and normal ESS scores are displayed in Table 22. Figure 73 presents additional information about the proportion of on-watch time below criterion for the different categories. As shown in Table 23, the difference in the proportion of on-watch time below criterion for participants with normal and elevated ESS scores was statistically significant. Participants with elevated ESS scores tended to spend a greater proportion of on-watch time below criterion than participants with normal ESS scores. This result adds validity to the argument that the ESS could be a useful tool for determining possible fatigue-related risk factors in watchstanders in order to provide the opportunity for administering countermeasures, such as naps or modifying watch rotations, in order to prevent errors and mishaps from occurring
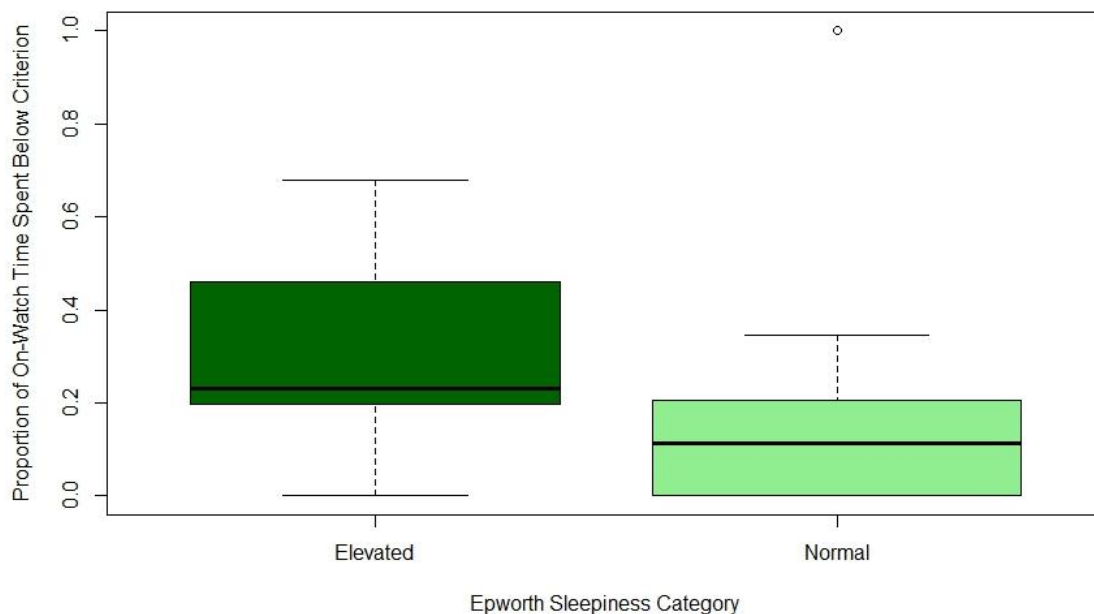
Figure 73.   Boxplot of the ratio of on-watch time spent below criterion and total on-watch time, delineated by ESS category.

b. *Composite Scale of Morningness*

The summary statistics for the proportion of on-watch time below criterion, based on CSM-determined chronotype, are displayed in Table 22. Figure 74 presents additional information about the proportion of on-watch time below criterion for the different chronotypes. As shown in Table 23, the difference in the proportion of on-watch time spent below criterion for participants of intermediate and morning chronotypes was not statistically significant.
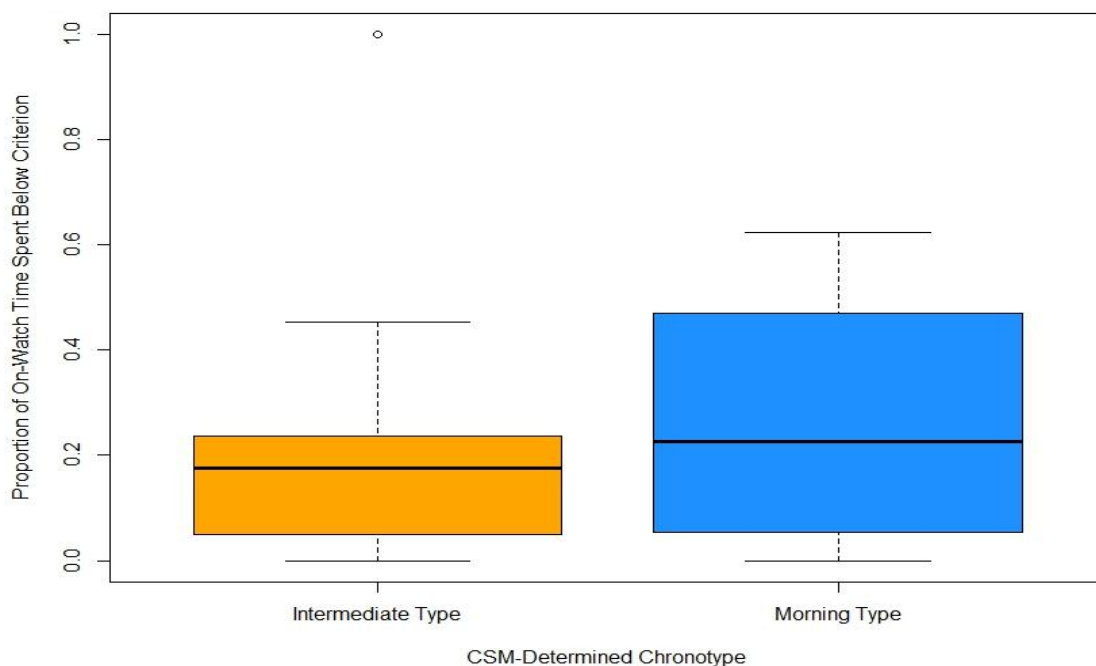
Figure 74.   Boxplot of the ratio of on-watch time spent below criterion and total on-watch time, delineated by CSM-determined chronotype.

This result was interesting because a statistically significant difference existed between the two groups' average daily sleep. One possible explanation could be that the large variability in participants' on-watch performance and the proportion of on-watch time spent below criterion, coupled with the small number of morning-type participants (n = 5), made detecting any statistical differences between the two groups difficult. Even though participants with a morning chronotype slept less, on average, than intermediate-type participants, perhaps

some factor other than the amount of sleep, such as sleep timing, caused the groups' on-watch predicted effectiveness and proportion of on-watch time below criterion to be similar. Thus, while intermediate-type participants show greater circadian flexibility in that they are able to receive, on average, more sleep each day, perhaps the sleep they are getting is poorly timed with respect to the time of day and their circadian rhythm, as well as their watch rotation. Additional research should be conducted in order to further investigate the possible causes for the differences in results between average daily sleep and predicted effectiveness for chronotype.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

While the U.S. Navy simultaneously reduces the number of U.S. ships and naval personnel, the fleet is assuming more missions and responsibilities. As a result, the operational tempo and demands placed on enlisted sailors and officers continues to increase. U.S. aircraft carriers, considered one of the most important military assets available to the President, are routinely called on to execute year-long deployments, with surge capability, in response to crises around the world. As a result, much is demanded of the crews of these warships. The decrease in manpower and increased pace of operations, coupled with the already challenging environment that naval personnel are required to work and live in while deployed, results in poor sleep, extreme fatigue, degraded performance, and often avoidable mistakes and mishaps. This thesis contributes to on-going studies of warfighter sleep, fatigue, and performance by analyzing the sleep, work schedules, and on-watch performance of the crew of the USS *Nimitz*.

The data analyzed in this thesis were collected at sea under operational conditions. The analysis of operational data is vital for confirming the applicability of existing sleep research for use by the U.S. Navy. However, by its nature, the data analyzed here is observational and not a result of a designed experiment.

1. Epworth Sleepiness Scale

The ESS was used to determine daytime sleepiness levels of the participants. Forty-seven percent of participants had elevated ESS scores, indicating that nearly half of the participants experienced high levels of daytime sleepiness. The majority of officers had normal ESS scores, whereas the split between the two categories for enlisted sailors was nearly even.

The analysis of ESS scores showed a strong statistical difference between officers and enlisted sailors. Officers tended to have lower ESS scores and less daytime sleepiness, as compared to enlisted sailors. The difference, however,

between the proportions of officers and enlisted sailors in the elevated and normal categories of ESS scores was not statistically different.

2. Composite Scale of Morningness

The CSM was used to determine participants' chronotypes. Twenty-five out of 32 (78%) of the participants were determined to be of intermediate chronotype, seven (22%) were determined to be of morning chronotype, and none were determined to be of evening chronotype. Although there was little overall correlation between CSM score and age, a strong negative correlation between enlisted sailor CSM score and age was found. There was little correlation between officer age and CSM score. The strong negative correlation for enlisted sailors is contradictory to a past study conducted by Roenneberg, Justice, et al. (2003), which found that after early adulthood, CSM scores tended to decrease (i.e., people tend to favor morningness as they age).

In Chapter IV, Section B.7.a, two possible explanations were proposed for the strong negative correlation between enlisted sailor age and CSM score and the prevalence of intermediate chronotype among the participants: psychological adaptation through cognitive dissonance reduction; and individuals with less circadian flexibility (i.e., strong morningness or eveningness preference types) may be more likely to get out of the Navy earlier in their careers. The results, coupled with these two explanations, lead to two important conclusions: (1) caution is warranted when using CSM as a means for determining naval personnel chronotypes in operational environments because psychological adaptation by individuals can cause deceiving results; and (2) circadian flexibility may affect long-term retention in the U.S. Navy.

The weak statistical difference in CSM scores between belowdecks and topside watchstanders, coupled with the fact that the Reactor Department, compared to the other departments, had significantly lower CSM scores, points to two conclusions: (1) exposure to natural light while on watch affects one's

circadian entrainment; and (2) the effect on circadian entrainment may be profound enough to cause a difference in CSM score between watchstation locations.

The finding that participants with morning chronotypes had statistically higher ESS scores, compared to those participants with intermediate chronotypes, and the finding that a statistically higher proportion of participants with morning chronotypes were determined to have elevated ESS scores, leads to two conclusions: (1) greater circadian flexibility leads to less daytime sleepiness as a result of sleep debt in naval operational environments; and (2) with regard to sleep and fatigue, individuals of intermediate chronotype may be better suited for operational Navy environments because they are better able to make use of irregular sleep opportunities.

3. Average Daily Sleep

The average daily sleep of participants was determined and analyzed in order to assess the amount of daily sleep participants received over the course of the data collection period. The 95% confidence interval for the median of average daily sleep was [6.3, 7.1]; however, 22/32 (69%) and 6/32 (19%) of participants received less than seven hours and less than six hours of sleep per day, respectively. These sleep levels certainly resulted in substantial sleep debt over the course of the data collection.

Participants with normal ESS scores received significantly more sleep than those participants with elevated scores. On average, participants with normal ESS scores received approximately one additional hour of sleep per day. This result is comparable to the findings of a previous study conducted by Shattuck and Matsangas (2014), which found that ESS scores correlated with PVT scores and daily sleep. ESS is a feasible method for measuring sleep-related fatigue of personnel in naval operational environments. Furthermore, since the ESS takes only two to three minutes to complete and is relatively

inexpensive to administer to personnel on ships, it provides a unique tool for quickly identifying fatigued personnel, allowing the opportunity for administering fatigue countermeasures.

Participants with a morning chronotype received significantly less sleep than participants with an intermediate chronotype. On average, intermediate-type participants slept over one hour more per day than morning-type participants. This finding is comparable to past studies that found later chronotypes (intermediate and evening) showed a higher tolerance for shiftwork (Duffy, Dijk, Hall, & Czeisler, 1999; Foster & Kreitzman, 2004; Harma, Tenkanen, Sjoblom, Alikoski, & Heinsalmi, 1998; Ostberg, 1973). Although participants with an intermediate chronotype still experienced sleep deprivation during the course of the data collection period, the fact that their average daily sleep was statistically higher than morning-type participants leads to two conclusions: (1) a person's predisposed chronotype affects the amount of sleep that they are able to receive on an operational warship at sea; and (2) personnel with greater circadian flexibility show greater tolerance for the rotating watch schedules traditionally employed by operational warships at sea.

4.   Day-to-Day Sleep

Participants were split into three different periods according to when they took part in the data collection. Each period was analyzed separately and then the periods were compared to assess potential differences. The majority of participants demonstrated highly inconsistent day-to-day sleep. For all the periods, there was little correlation between average daily sleep and the day-to-day variance of each participant's sleep. Thus, for the participants in this study, there was little connection between the consistency of one's sleep and the actual amount one slept over the course of the data collection period. The main conclusion to be drawn from these results is that average daily sleep can be deceiving when analyzing the sleep habits of personnel in operational units at sea. Often, individuals rely on a single period of extended sleep (in excess of

eight hours) or "binge sleep," in an attempt to recover from several days of severe sleep debt. Unfortunately, as a study by Belenky et al. (2003) has shown, recovery from even modest amounts of sleep debt in a single extended sleep period is not possible.

In this study, participants in the Reactor Department were the biggest culprits of "binge sleeping." The average sleep of all participants from the Reactor Department was statistically greater on Sundays than all other days of the week, demonstrating a clear day-of-the-week effect with regard to day-to-day sleep. The department systematically sleep-deprived its personnel throughout the week and adopted a "holiday" routine on Sundays in order to provide its personnel with only a single day to recover from six days of minimal sleep. Thus, unknowingly, this department routinely forced personnel to stand watch while extremely fatigued, and put the ship and its crew in danger on a daily basis.

Overall, the officers had significantly more consistent day-to-day sleep than the Reactor Department. Furthermore, there was not a day-of-the-week effect present for the officers. The officers, on a much more favorable 4ON/20OFF watch schedule, compared to the 5ON/15OFF schedule adopted by the Reactor Department, clearly demonstrated more consistent sleep. This finding is interesting because although the median of officer average daily sleep was only 24 minutes greater than that of Reactor Department participants, 57% (8/14) of the Reactor Department participants had elevated ESS scores, as compared to only 27% (3/11) for officers. The more favorable overall ESS scores of officers can be, at least in part, linked to the more consistent day-to-day sleep they received. These results again highlight the utility of the ESS in determining sleep-related fatigue of personnel in operational units.

The most important conclusion to draw from the analysis of day-to-day sleep is that overall the participants had poor "sleep hygiene." Sleep hygiene, as defined by the NSF (2014b), is a "variety of different practices that are necessary to have normal, quality nighttime sleep and full daytime alertness" to include avoiding daytime naps and stimulants, establishing a regular relaxing bedtime

routine, adequate exposure to natural light, and ensuring that the sleep environment is pleasant (para. 1, para. 3). Unfortunately, few, if any, of the participants' sleep habits demonstrated any of these characteristics.

5. Navy Standard Workweek

The work and sleep schedules of the participants were analyzed and compared to the NSWW to determine the utility of the NSWW in informing manpower decisions for U.S. aircraft carriers. The NSWW categories with the greatest deviation from the NSWW-allotted times were free time, maintenance and work, and meetings and service diversions. The greatest overall deviation was for the maintenance and work category.

For participants in this study, 73% exceeded the 14 hours per week of time allocated for maintenance and work in the NSWW. On average, participants worked 18.3 hours per week more than they were allotted in the NSWW, or 2.6 hours more per day. Additionally, 85% of participants slept less than the 56 hours of time allocated in the NSWW and, on average, slept 7.7 hours less than the NSWW-allotted time, or 1.1 hours less per day. Interestingly, only one participant stood more watch than the 56 hours allocated in the NSWW and, on average, participants stood watch 20.3 hours less per week than the NSWW-allotted time, or 2.9 hours less per day. Overall, on-watch time did not account for a substantial portion of participants' daily routines. However, 65% of participants exceeded the four hours of time allotted in the NSWW for meetings and service diversions. On average, participants spent 5.8 hours more per week in meetings and service diversions, or 0.8 hours more per day, than they were allotted in the NSWW. Clearly, the amount of maintenance and work that participants were required to complete, coupled with the significant amount of time that participants had to spend in meetings and responding to unplanned events (service diversions) reduced the amount of time available for sleep. The small deviation from the NSWW category of watch and the large deviations between the NSWW and the two categories of maintenance and work and meetings and service diversions

suggest that the NSWW does not accurately reflect the demands placed on today's sailors and officers. Determining aircraft carrier manning levels cannot be based solely on watchstation manning alone, but maintenance requirements and the potential for unplanned events and other daily activities must also be considered. Thus, more complex tools, such as IMPRINT Pro, must be utilized for doing so.

The fact that the Deck Department reported the most free time, yet also was the statistically youngest department, led to the analysis of the amount of reported free time as a function of age. A weak negative correlation between average daily free time and age was found. As the age of participants increased, the amount of average daily free time that they reported decreased. Since the Deck Department's average daily sleep and ESS scores did not differ substantially from the other departments, yet they had the most free time, suggests the following possible conclusions: (1) young sailors demonstrate poor time management skills when not given specific tasks; and (2) young sailors, although possessing more opportunities to sleep (i.e., free time), may not be able do so as a result of the numerous issues associated with rotating watch schedules and the work schedules used on operational surface ships.

6.   Comparison of Self-Reported and Actigraphic Sleep

Actigraphic sleep was compared to the self-reported sleep of the participants. Overall, actigraphic sleep was statistically significantly less than self-reported sleep. Participants tended to over-report the amount of sleep that they received during the data collection period. This initial finding suggests that, in operational environments, one may tend to overestimate the amount of sleep received on a daily basis; however, self-reported sleep can still be a useful tool, since it provides an additional method for corroborating actigraphic sleep data.

The findings from the comparison of actigraphic and self-reported sleep differ from that of a previous study conducted by Lauderdale et al. (2009) which found a moderate correlation between actigraphic and self-reported sleep and

that only 20% of the variation in actigraphic sleep data could be explained by self-reported sleep. A stronger correlation between actigraphic and self-reported sleep data was found in the *Nimitz* data and a greater amount of the variation in actigraphic sleep data was explained by the self-reported sleep data. These findings suggest that self-reported sleep may actually be more accurate in U.S. Navy operational environments than in other civilian-type sleep studies and, although actigraphic data is preferred, self-reported sleep data can provide useful insights into the sleep habits of warfighters at sea.

In order to determine the effect of different levels of sleep debt on the self-reporting of sleep, study participants were split into three groups. These groups were based on the amount of actigraphic sleep participants received: greater than eight hours, between six and eight hours, and less than six hours. Based on this analysis, participants that received between six and eight hours of sleep, on average, most accurately self-reported their sleep, while participants that slept less than six hours were least accurate. The participants sleeping greater than eight hours, on average, tended to under-report their sleep, while the other two groups tended to over-report their sleep. Additionally, the group that reported receiving greater than eight hours of sleep showed the greatest variability in the accuracy of self-reported sleep. The findings in this thesis differ from a previous study, which found that at the actigraphic mean of six hours, self-reported and actigraphic sleep differed the most (Lauderdale, Knutson, Yan, & Rathouz, 2008). The results of the *Nimitz* study suggest that the largest difference occurs in participants receiving less than six hours of sleep, on average. These findings suggest that: (1) personnel suffering from severe sleep debt, as a method of cognitive dissonance reduction, may attempt to psychologically adapt by over-reporting their sleep; and (2) sleep-related fatigue negatively affects one's ability to assess the amount of sleep that they are getting. The fatigued brain cannot judge its impairment.

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7.   SAFTE-FAST Analysis

SAFTE-FAST was used to determine participants' on-watch predicted effectiveness and the proportion of on-watch time participants spent below the criterion level of 77.5. This criterion level is equivalent to a BAC of approximately 0.05 and is the level at which the USAF requires the application of fatigue countermeasures. Officers tended to have a higher on-watch predicted effectiveness than enlisted sailors. Even though officers tended to receive slightly more sleep (24 minutes per day, on average), the difference was not determined to be statistically significant. Officers' on-watch predicted effectiveness, however, was significantly greater than that of enlisted sailors. Additionally, although Reactor Department personnel on average received a similar amount of daily sleep, compared to the other departments, the on-watch predicted effectiveness of participants from the Reactor Department was significantly less than that of the other departments. The difference in the results between average daily sleep and on-watch predicted effectiveness is important, as it suggests that: (1) average daily sleep can be a deceiving measure of the effects of sleep-related fatigue when not analyzed along with other factors, such as sleep-timing and circadian effects; (2) since the participants of the Reactor Department demonstrated the least consistent day-to-day sleep of any department and systematically became sleep deprived on a weekly basis, sleep consistency and overall "sleep hygiene" affect on-watch performance; and (3) the reliance on Sunday "binge sleep" by the Reactor Department negatively affected their on-watch performance, demonstrating the futility of such efforts in naval operational environments.

There were significant differences between the on-watch predicted effectiveness of participants with elevated and normal ESS scores. Participants with normal ESS scores tended to have higher on-watch predicted effectiveness scores. Additionally, the difference between the two groups in the proportion of on-watch time spent below criterion was statistically significant. Participants with normal ESS scores tended to spend a smaller proportion of time on-watch below criterion level. These findings demonstrate the usefulness of the ESS in not only

determining personnel that may be fatigued due to sleep-related issues, but also as a quick and efficient method for determining individuals at-risk for low on-watch performance. ESS can be an effective tool for discriminating between individuals ready to perform not just at the start of watch and other critical tasks, but for the majority of time during which an evolution is to be carried out.

Although participants of intermediate chronotype tended to get more sleep than morning-type participants, there was not a significant difference between the groups with regard to on-watch predicted effectiveness and the proportion of on-watch time spent below criterion. The difference between these findings suggests that although greater circadian flexibility may result in personnel receiving a greater amount of average daily sleep, it does not guarantee higher on-watch performance levels. Other factors, such as sleep timing and circadian effects, play an important role in determining an individual's on-watch performance levels, and must be taken into account when developing watch rotations and work schedules.

B.   RECOMMENDATIONS

The recommendations set forth in this thesis aim to inform U.S. Navy leadership and shape the direction of future research with regard to sleep, fatigue, performance, work schedules, and manpower planning. Although much work has already been accomplished in this field of research, the recommendations in this thesis seek to add to the already detailed and often already implemented recommendations proposed by past NPS theses.

1.   Recommendations for U.S. Navy Leadership

There are a myriad of sleep, fatigue, and performance analysis and diagnostic tools available that are currently being underutilized by the U.S. Navy. First, the ESS should be implemented as a tool for monitoring sleep-related fatigue and performance issues on all surface ships and submarines. Since it will cost very little and pose a minimal burden on the crew of any ship, having

personnel complete the ESS survey could be a useful and simple method for identifying watchstanders that are at risk of being overly fatigued and potentially having low on-watch performance.

Second, as chronotype affects the amount of sleep participants received and their ESS scores, diurnal preference needs to be taken into account as a possible factor in Navy recruitment and retention. CSM and MEQ should be administered to all personnel in the Navy and used as a tool for identifying and educating potentially "at-risk" individuals. Navy personnel with a morning diurnal preference are at a disadvantage, compared to personnel with greater circadian flexibility, with regard to not only the amount of sleep they get and their daytime fatigue levels, but possibly also with regard to retention rates. Implementing mandatory training with regard to sleep hygiene and the warning signs and symptoms of sleep debt and sleep deprivation for all ranks, especially young enlisted sailors, division officers, and senior enlisted leaders, would be beneficial. This training should also encompass educating personnel on diurnal preference, giving personnel the opportunity to determine their chronotype, and to tailor education based on chronotypes.

SAFTE-FAST is a relatively simple, yet robust, tool that can be used to determine and predict the on-watch effectiveness of naval personnel on operational units at sea. Unfortunately, it is being woefully underutilized throughout the U.S. Surface Navy. Even though SAFTE-FAST is not specifically tailored for maritime use, it is the only modeling tool that is validated against PVT data and can quickly, even with limited or no data, provide an estimate of a watchstander's effectiveness levels prior to, during, and after watch.

Guidance should be provided to all operational commands mandating the use of SAFTE-FAST when designing watch rotations in order to determine the predicted effectiveness levels of watchstanders. Furthermore, SAFTE-FAST should be used in the investigation of all near misses, mishaps, and accidents in all Navy units. In order to effectively implement SAFTE-FAST as a useful tool, Navy leadership must also mandate, develop, and provide training on SAFTE-

FAST. This training must go beyond simply exposing personnel to SAFTE-FAST's potential uses. Rather, this training must educate potential future users about circadian rhythms, sleep architecture, human performance and its relationship to fatigue, and, most certainly, how to effectively use and employ SAFTE-FAST in operational environments.

The NSWW is an inadequate tool for informing manpower decision makers. Basing complex manpower decisions on a scheme of outdated categories and time allocations is a naïve approach. If the NSWW is going to continue to be a tool used for manpower planning, it must be altered to accurately reflect the tremendous amount of time that sailors and officers spend conducting maintenance, working and attending meetings, and responding to unplanned events. The key driver for determining manning levels should not always be the number and type of watchstations that need to be filled. Rather, the amount of work and other requirements outside of watch need to be emphasized in any new NSWW or equivalent planning tool. A single type of NSWW cannot be used for informing manpower decisions for all platforms and rates. Instead, individualized or tailored NSWWs should be developed for different types of ships and rates. Other tools, such as the IMPRINT Pro Forces Module, which is a stochastic event simulation tool designed by the Army specifically for informing manpower decisions, should be considered as a possible tool to supplement the NSWW.

2. Recommendations for Future Research

In order to generalize the results of the ESS and CSM findings from this thesis, larger studies of personnel, in several different types of operational environments and on different types of naval platforms, need to be conducted. Furthermore, a Navy-wide study of personnel chronotypes should be performed in order to determine any potential connection between diurnal propensity and retention.

Although the Navy is already developing alternate methods for informing manpower decisions, detailed and large-scale studies of daily routines of naval personnel, compared to the NSWW, still need to be conducted. Future research should use this data as an input for IMPRINT Pro to investigate the effect of different manning levels on fatigue, individual performance, and unit performance. The results of such analyses should then be compared to the current NSWW, allowing for more detailed recommendations for developing tools for manpower planning.

Additional studies of at-sea operational units involving the use of SAFTE-FAST, in conjunction with PVT and actigraphic data, are needed to validate SAFTE-FAST for maritime use. Doing so would only serve to substantiate the use of SAFTE-FAST for evaluating the sleep, fatigue, performance, and work schedules of naval personnel while deployed at sea.

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APPENDIX A.   DEMOGRAPHIC QUESTIONNAIRE

Participant ID: _____   Date: _____

Demographic Questionnaire

1. Age: _____

2. Gender: (Check one)   ____Male   ____Female

3. Rate: (for example, FC, HT, OS, IT, GSE)_____

4. Rank: (for example, E4, O2) _____

5. How many years have you been on active duty? _____

6. Have you been deployed on other ships in the past? (Check one)   ___Yes   ___No

    If Yes,

    How many times and for how long have you been deployed? _____

7. Prior to this deployment, have you stood watch while underway? (Check one)   ___Yes   ___No

    If Yes,

    What watch rotations were you standing on these prior deployments? _____

    Where were you standing watch on these prior deployments? _____

8. Are you standing watch during this underway deployment? (Check one)   ___Yes   ___No

    If Yes,

    What section of the watch bill were you on? _____

    What department do you work in? _____

    Where do you stand watch? _____

5. What deck is your current berthing located on? (for example 02, 1 etc.) _____

6. What part of the ship is your berthing currently located (check one)?
    ☐ Forward   ☐ Amidships   ☐ Aft

7. How is your rack currently oriented (check one)
    ☐ Across the ship, port to starboard or athwart the ship
    ☐ Lengthwise with respect to the ship, fore and aft or abeam the ship

8. What kinds of things affect your sleep on the ship?   (Check all that apply)

☐ **Not enough time to sleep**

☐ **Noise** (_____Other Sailors   _____ Engine/equipment noise)

☐ **Temperature** (_____too cold ____too hot)

☐ **Light**

☐ **Motion**

☐ **Bedding Conditions** ____Bunk Length ____Mattress ____Pillow ____Curtain

☐ **Odors** (____engine fumes   ____human odors)

9. How many of the following **caffeinated** beverages do you drink on average each day?
(Check all that apply and indicate daily amount)

☐ **Tea** (Servings/Cups: _____)

☐ **Coffee** (Servings/Cups: _____)

☐ **Soda/pop/soft drinks** (Servings/Cups: _____)

☐ **Monster/RedBull** (Servings/Cups: _____)

☐ **5 Hour Energy** (Servings/Cups: _____)

☐ **Other (specify):** _____ (Servings/Cups: _____)

10. Which of the following nicotine products do you use?
(Check all that apply and indicate how often)

☐ **Cigarettes** (How often? _____)

☐ **Chewing tobacco/snuff** (How often? _____)

☐ **Nicorette gum or patches** (How often? _____)

☐ **Electronic smoke** (How often? _____)

☐ **Other (specify):** _____ (How often? _____)

11. Do you take any over-the-counter medications on a daily basis? **(Check one)**   ___Yes   ___No

   If **Yes,** Please list all over-the-counter medications you take: _____

   _____

12. Do you have an exercise routine? **(Check one)**   ___ Yes   ___ No

   If **Yes,**

   How often do you do it?   ____Daily   ____Times per week (for example, 3 Times per week)

   What kind of exercise routine do you do? _____

   How long does this routine take you? _____

APPENDIX B.   END-OF-STUDY QUESTIONNAIRE

End of Study Questionnaire
1. Were you standing watch during this underway deployment? (Check one)   ___Yes
    ____No

    If <u>Yes</u>,

        What department do you work in?
        _____
        Which watch standing rotation were you on for the <u>majority</u> of your deployment (hours
on/hours off)?

☐	5/10	☐	6/18
☐	5/15	☐	12/12
☐	6/6	☐	Other
☐	6/12		(describe)_____/_____

        What section of the watch bill were you working (section #)?
        _____
        Where did you stand watch (ex: CIC, Bridge, etc.)?
    _____

2. Did anything about your watch schedule change since you started wearing the sleep watch?

    (Check one)

        ☐   Yes
        ☐   No

    If <u>Yes</u>,

        Please describe any changes to your watch schedule that occurred since you started
        wearing the sleep
        watch._____
        _____

3. Did you have any collateral duties during this underway? (Check one)   ___Yes ____No

    If <u>Yes</u>,

    What kind of collateral duties?

    _____

4. The amount of sleep I received on my current watch bill was: (Check one)
☐much less than   ☐less than   ☐about   ☐more than   ☐much more than needed
needed   needed   right   needed

5. The amount of sleep received by the other Sailors on this cruise seemed: (Check one)

☐much less than   ☐less than   ☐about   ☐more than   ☐much more than needed
needed   needed   right   needed

6. How did your workload for the study period compare to your normal workload when deployed? (Check one)

☐much less than usual   ☐less than usual   ☐about the same   ☐more than usual   ☐much more than usual

7. What did you like most about your current watch rotation?

_____
_____
_____
_____
_____
_____
_____

8. What did you like least about your current watch rotation?

_____
_____
_____
_____
_____
_____
_____

9. Were there any challenges in implementing your current watch rotation?

_____
_____
_____
_____
_____
_____
_____

10. Is there anything else you would like to tell us (good or bad) about your current watch rotation?

_____
_____
_____
_____
_____
_____
_____

11. What advice would you give to others who would like to improve their watchstanding schedules?

_____
_____
_____
_____
_____
_____
_____

12. What deck is your current berthing located on? (for example 02, 1 etc.)

_____

13. What part of the ship is your berthing currently located?

□ Forward   □Amidships □Aft
14. How is your rack currently oriented (check one)
    □ Across the ship, port to starboard or athwart the ship
    □ Lengthwise with respect to the ship, fore and aft or abeam the ship

15. What kinds of things affect your sleep on the ship? (Check all that apply)

☐ Not enough time to sleep

☐ Noise (_____Other Sailors _____ Engine/equipment noise)

☐ Temperature (_____too cold _____too hot)

☐ Light

☐ Motion

☐ Bedding Conditions ____Bunk Length ____Mattress ____Pillow ____Curtain

☐ Odors (____engine fumes ____human odors)

☐ Other:

_____
_____
_____
_____

Thank you for participating in the USS NIMITZ Sleep Study!

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APPENDIX C.   PITTSBURGH SLEEP QUALITY INDEX

From Buysse, Reynolds, Monk, Berman, & Kupfer, 1989b.

~~Subject's Name~~_____ID#_____Date_____Time_____ AM / PM

PITTSBURGH SLEEP QUALITY INDEX

INSTRUCTIONS:
The following questions relate to your usual sleep habits during the past month <u>only</u>. Your answers should indicate the most accurate reply for the <u>majority</u> of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night?

    BED TIME _____

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

    NUMBER OF MINUTES _____

3. During the past month, what time have you usually gotten up in the morning?

    GETTING UP TIME _____

4. During the past month, how many hours of <u>actual sleep</u> did you get at night? (This may be different than the number of hours you spent in bed.)

    HOURS OF SLEEP PER NIGHT _____

For each of the remaining questions, check the one best response. Please answer <u>all</u> questions.

5. During the past month, how often have you had trouble sleeping because you . . .

a) Cannot get to sleep within 30 minutes

    Not during the   Less than   Once or twice   Three or more
    past month_____   once a week_____   a week_____   times a week_____

b) Wake up in the middle of the night or early morning

    Not during the   Less than   Once or twice   Three or more
    past month_____   once a week_____   a week_____   times a week_____

c) Have to get up to use the bathroom

    Not during the   Less than   Once or twice   Three or more
    past month_____   once a week_____   a week_____   times a week_____

d)   Cannot breathe comfortably

Not during the   Less than   Once or twice   Three or more
past month_____   once a week_____   a week_____   times a week_____

e)   Cough or snore loudly

Not during the   Less than   Once or twice   Three or more
past month_____   once a week_____   a week_____   times a week_____

f)   Feel too cold

Not during the   Less than   Once or twice   Three or more
past month_____   once a week_____   a week_____   times a week_____

g)   Feel too hot

Not during the   Less than   Once or twice   Three or more
past month_____   once a week_____   a week_____   times a week_____

h)   Had bad dreams

Not during the   Less than   Once or twice   Three or more
past month_____   once a week_____   a week_____   times a week_____

i)   Have pain

Not during the   Less than   Once or twice   Three or more
past month_____   once a week_____   a week_____   times a week_____

j)   Other reason(s), please describe_____

_____

How often during the past month have you had trouble sleeping because of this?

Not during the   Less than   Once or twice   Three or more
past month_____   once a week_____   a week_____   times a week_____

6.   During the past month, how would you rate your sleep quality overall?

Very good   _____

Fairly good   _____

Fairly bad   _____

Very bad   _____

7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?

Not during the _____   Less than _____   Once or twice _____   Three or more _____
past month   once a week   a week   times a week

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the _____   Less than _____   Once or twice _____   Three or more _____
past month   once a week   a week   times a week

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all   _____

Only a very slight problem   _____

Somewhat of a problem   _____

A very big problem   _____

10. Do you have a bed partner or room mate?

No bed partner or room mate   _____

Partner/room mate in other room   _____

Partner in same room, but not same bed   _____

Partner in same bed   _____

If you have a room mate or bed partner, ask him/her how often in the past month you have had . . .

a) Loud snoring

Not during the _____   Less than _____   Once or twice _____   Three or more _____
past month   once a week   a week   times a week

b) Long pauses between breaths while asleep

Not during the _____   Less than _____   Once or twice _____   Three or more _____
past month   once a week   a week   times a week

c) Legs twitching or jerking while you sleep

Not during the _____   Less than _____   Once or twice _____   Three or more _____
past month   once a week   a week   times a week

d) Episodes of disorientation or confusion during sleep

| Not during the past month | Less than once a week | Once or twice a week_____ | Three or more times a week_____ |

e) Other restlessness while you sleep; please describe_____

_____

| Not during the past month_____ | Less than once a week_____ | Once or twice a week_____ | Three or more times a week_____ |

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APPENDIX D.   EPWORTH SLEEPINESS SCALE

From Johns, 1991b.

ID#

Date: _____

Epworth Sleepiness Scale

This scale is designed to determine how likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired. This refers to your usual way of life in recent times. Even if you have not done some of these things recently try to think about how they would have affected you. Use the following scale to choose the most appropriate number for each situation:

0 = no chance of dozing
1 = slight chance of dozing
2 = moderate chance of dozing
3 = high chance of dozing

SITUATION	CHANCE OF DOZING
Sitting and reading	_____
Watching TV	_____
Sitting inactive in a public place (e.g a theater or a meeting)	_____
As a passenger in a car for an hour without a break	_____
Lying down to rest in the afternoon when circumstances permit	_____
Sitting and talking to someone	_____
Sitting quietly after a lunch without alcohol	_____
In a car, while stopped for a few minutes in traffic	_____

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APPENDIX E.   COMPOSITE SCALE OF MORNINGNESS

After Smith et al., 1989.

Composite Scale of Morningness and Eveningness

ID Number _____   Date _____

DIRECTIONS: Please *check* the response for *each* item that best describes *you*.

1. Considering only your own "feeling best" rhythm, at what time would you get up if you were entirely free to plan your day?

       5:00-6:30 AM   _____
       6:30-7:45 AM   _____
       7:45-9:45 AM   _____
       9:45-11:00 AM   _____
       11:00 AM-12:00 (noon)   _____

2. Considering your own "feeling best" rhythm, at what time would you go to bed if you were entirely free to plan your evening?

       8:00-9:00 PM   _____
       9:00-10:15 PM   _____
       10:15 PM-12:30 AM   _____
       12:30-1:45 AM   _____
       1:45-3:00 AM   _____

3. Assuming normal circumstance, how easy do you find getting up in the morning? (Check one.)

       Not at all easy   _____
       Slightly easy   _____
       Fairly easy   _____
       Very easy   _____

4. How alert do you feel during the first half hour after having awakened in the morning? (Check one.)

       Not at all alert   _____
       Slightly alert   _____
       Fairly alert   _____
       Very alert   _____

5. During the first half hour after having awakened in the morning, how tired do you feel? (Check one.)

       Very tired   _____
       Fairly tired   _____
       Fairly refreshed   _____
       Very refreshed   _____

6. You have decided to engage in some physical exercise. A friend suggests that you do this one hour twice a week and the best time for him is 7:00-8:00 AM. Bearing in mind nothing else but your own "feeling best" rhythm, how do you think you would perform?

      Would be in good form   _____

      Would be in reasonable form _____

      Would find it difficult   _____

      Would find it very difficult   _____

7. At what time in the evening do you feel tired and, as a result, in need of sleep?

      8:00-9:00 PM   _____

      9:00-10:15 PM   _____

      10:15 PM-12:30 AM   _____

      12:30-1:45 AM   _____

      1:45-3:00 AM   _____

8. You wish to be at your peak performance for a test which you know is going to be mentally exhausting and lasting for two hours. You are entirely free to plan your day, and considering only your own "feeling best" rhythm, which ONE of the four testing times would you choose?

      8:00-10:00 AM   _____

      11:00 AM-1:00 PM   _____

      3:00-5:00 PM   _____

      7:00-9:00 PM   _____

9. One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be?

      Definitely a morning type   _____

      More a morning than an evening type   _____

      More an evening than a morning type   _____

      Definitely an evening type   _____

10. When would you prefer to rise (provided you have a full day's work—8 hours) if you were totally free to arrange your time?

      Before 6:30 AM   _____

      6:30-7:30 AM   _____

      7:30-8:30 AM   _____

      8:30 AM or later   _____

11. If you always had to rise at 6:00 AM, what do you think it would be like?

      Very difficult and unpleasant   _____

      Rather difficult and unpleasant   _____

      A little unpleasant but no great problem   _____

      Easy and not unpleasant   _____

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12. How long a time does it usually take before you "recover your senses" in the morning after rising from a night's sleep?

      0-10 minutes   _____

      11-20 minutes   _____

      21-40 minutes   _____

      More than 40 minutes _____

13. Please indicate to what extent you are a morning or evening *active* individual.

      Pronounced morning active (morning alert and evening tired)   _____

      To some extent, morning active   _____

      To some extent, evening active   _____

      Pronounced evening active (morning tired and evening alert)   _____

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APPENDIX F.   DAY-TO-DAY SLEEP PLOTS

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Participant 2

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Participant 3

Participant 4

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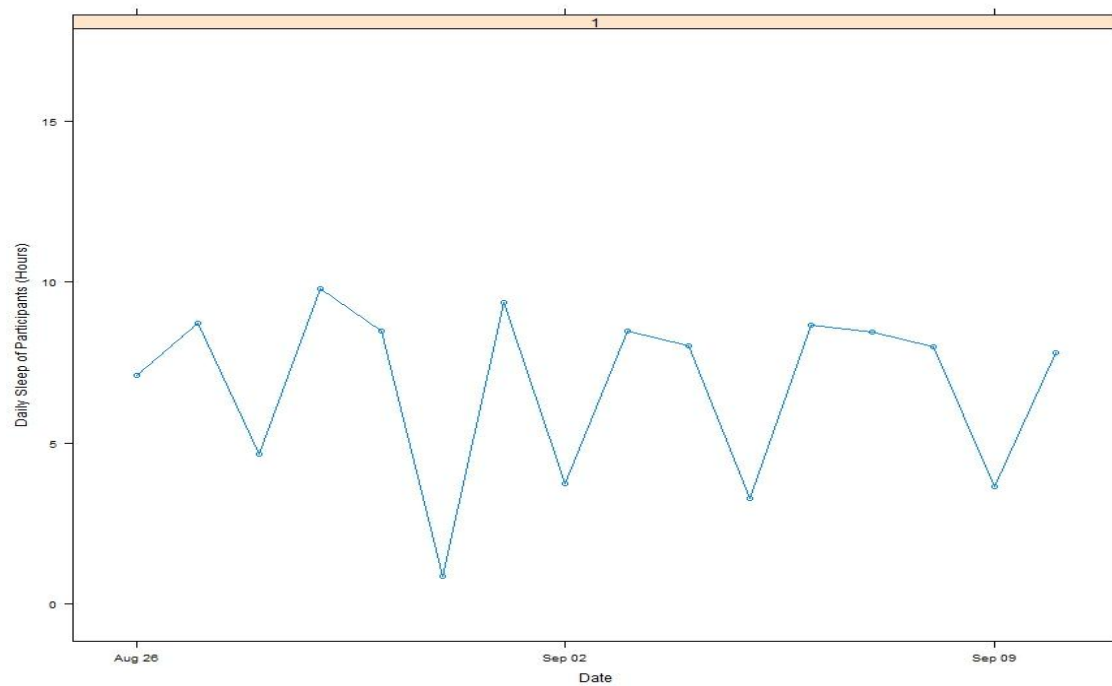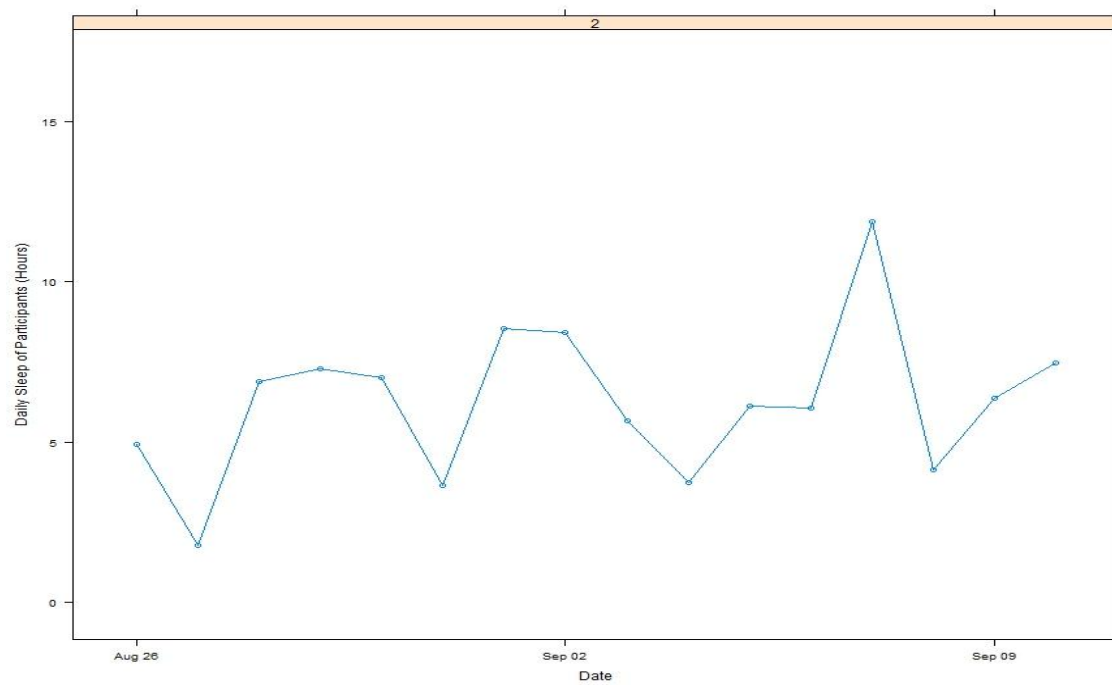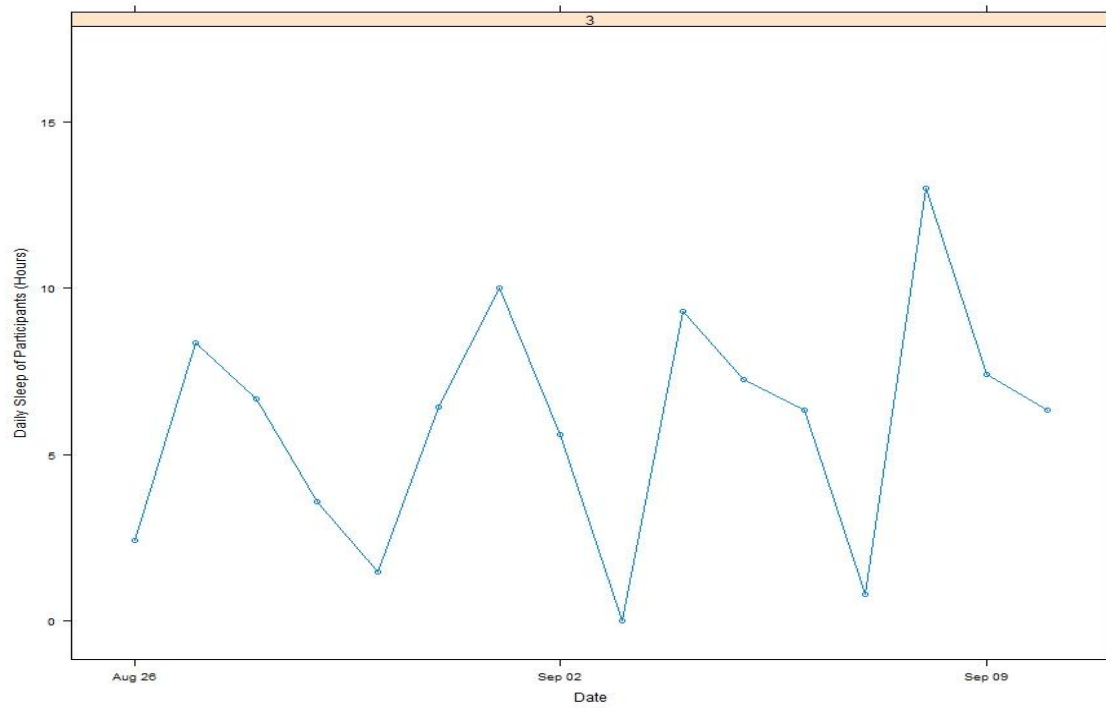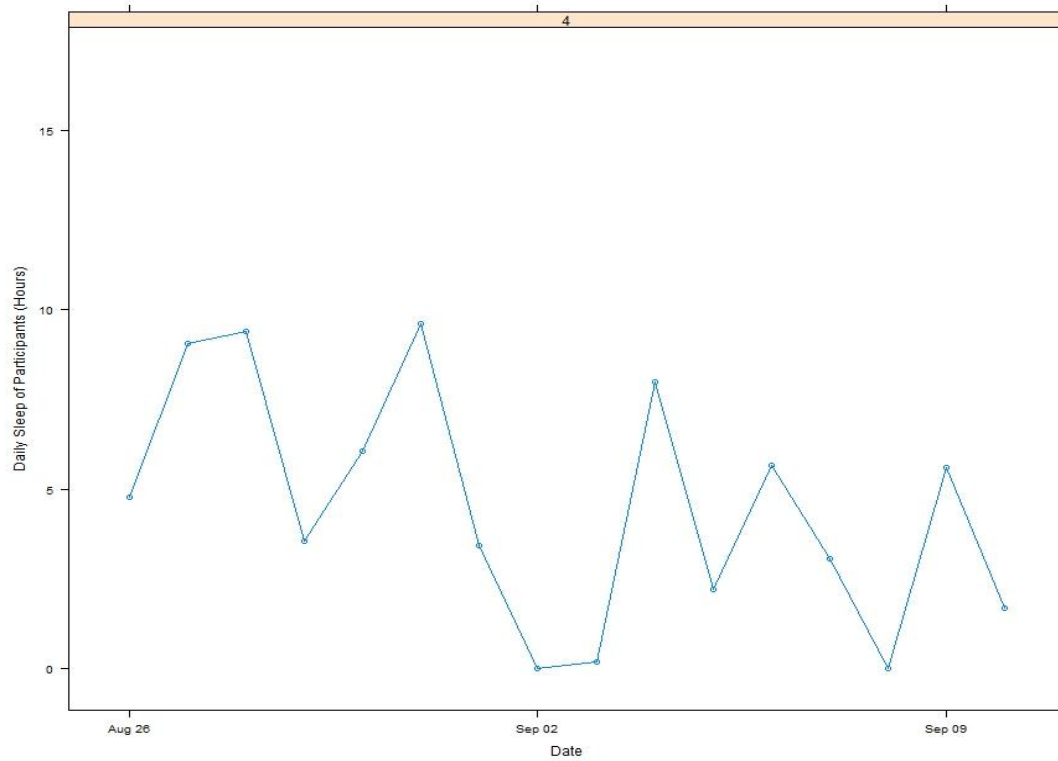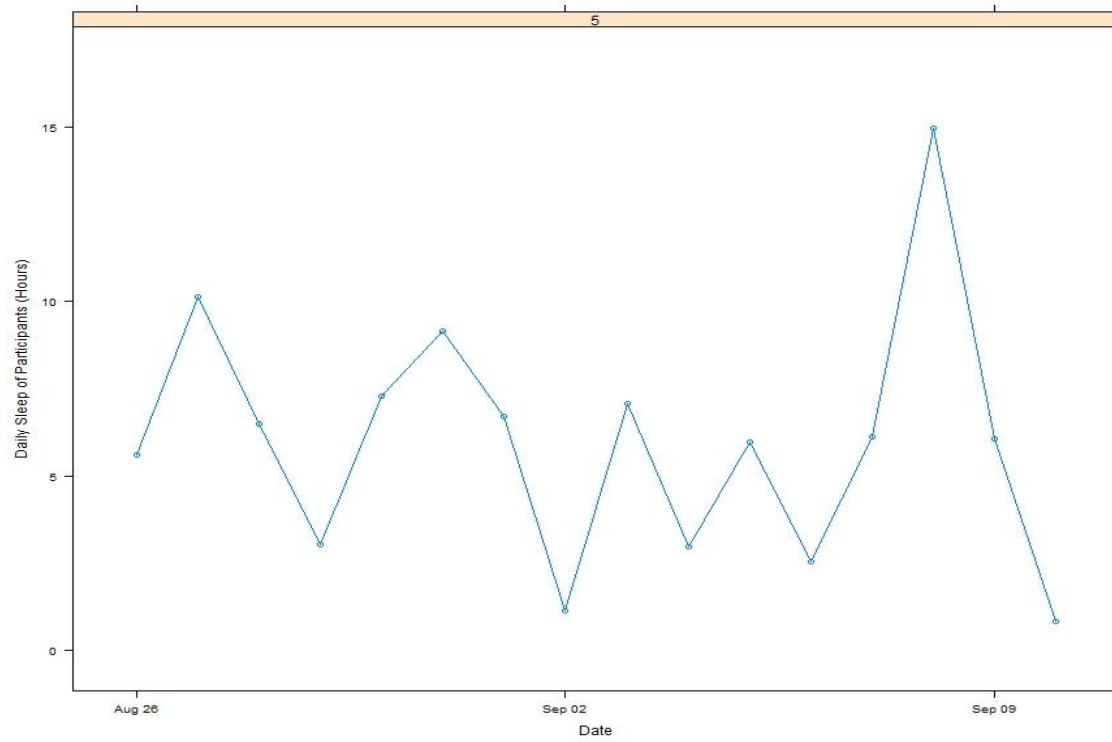
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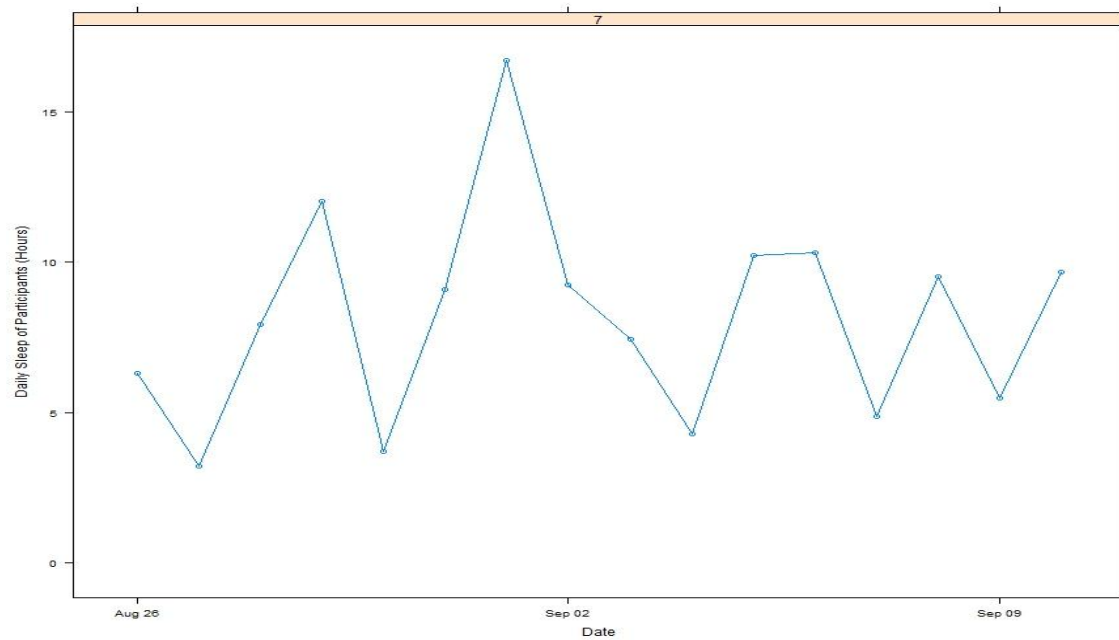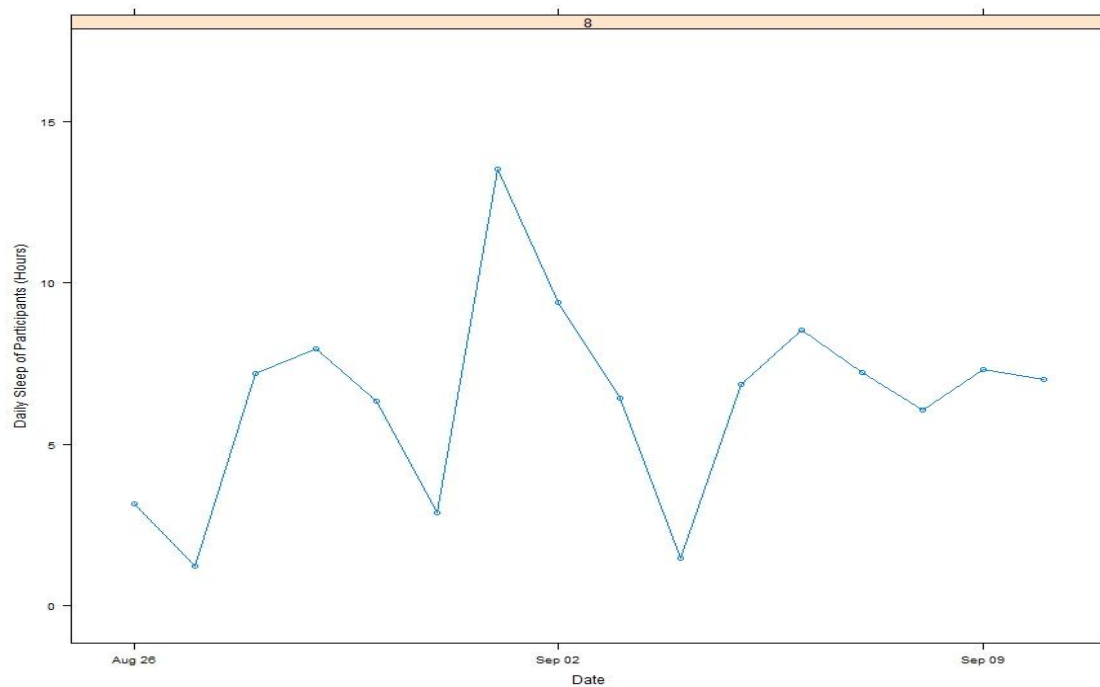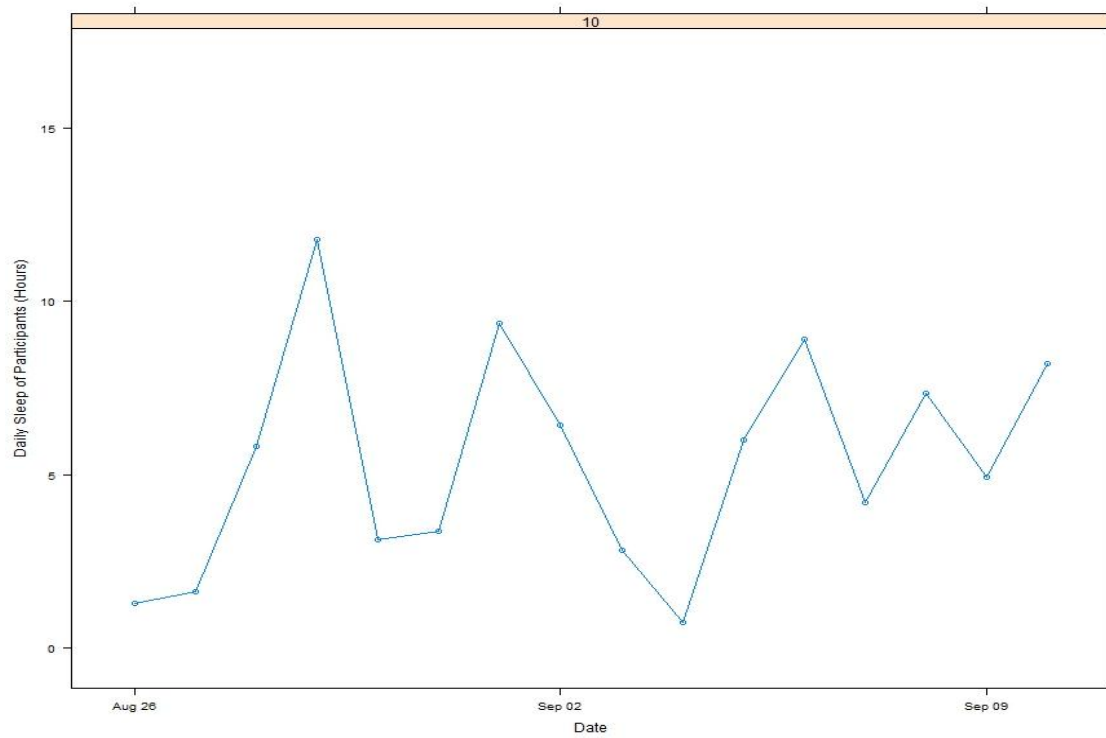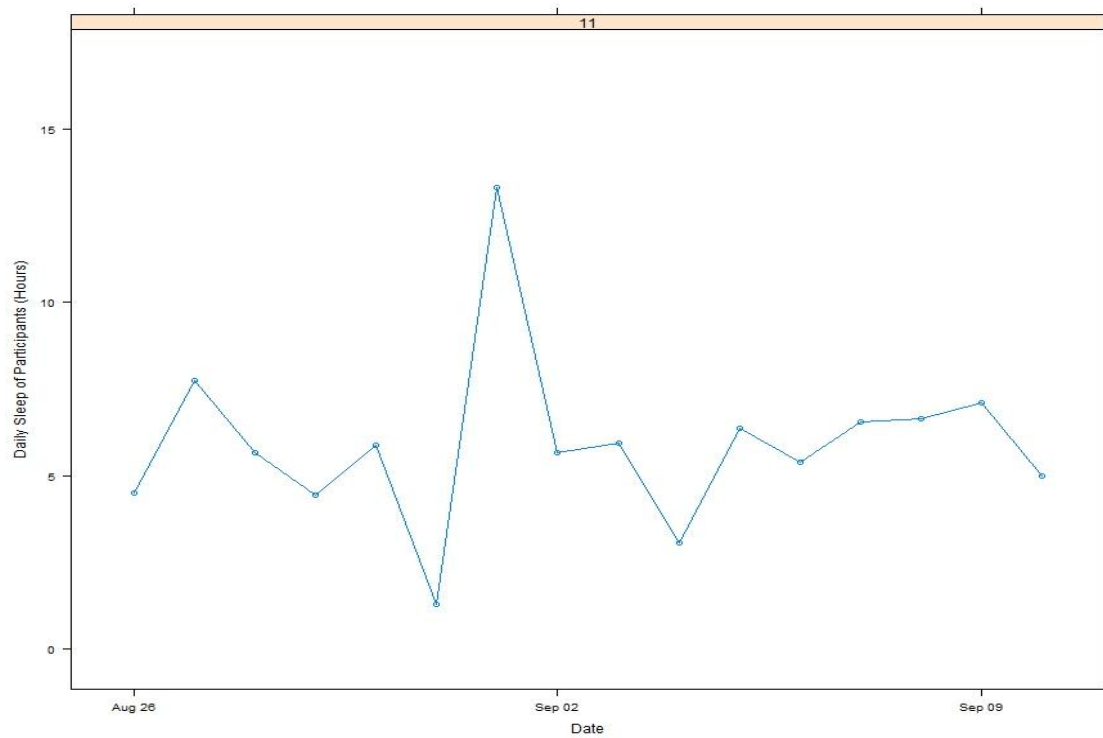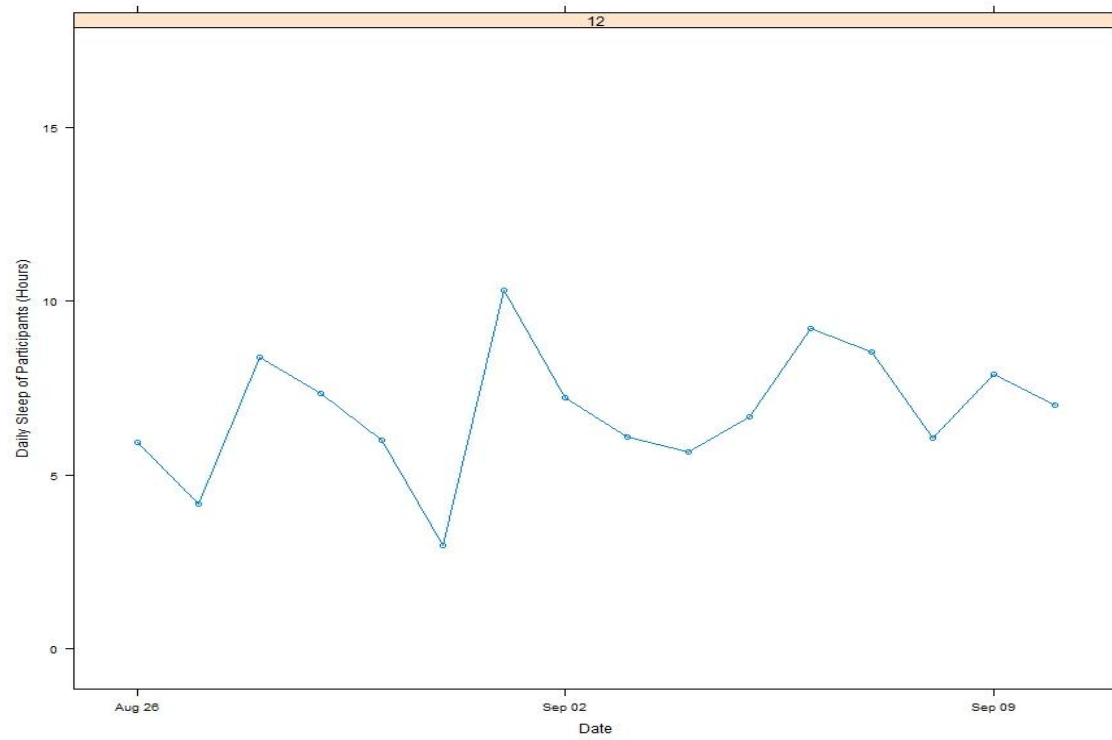
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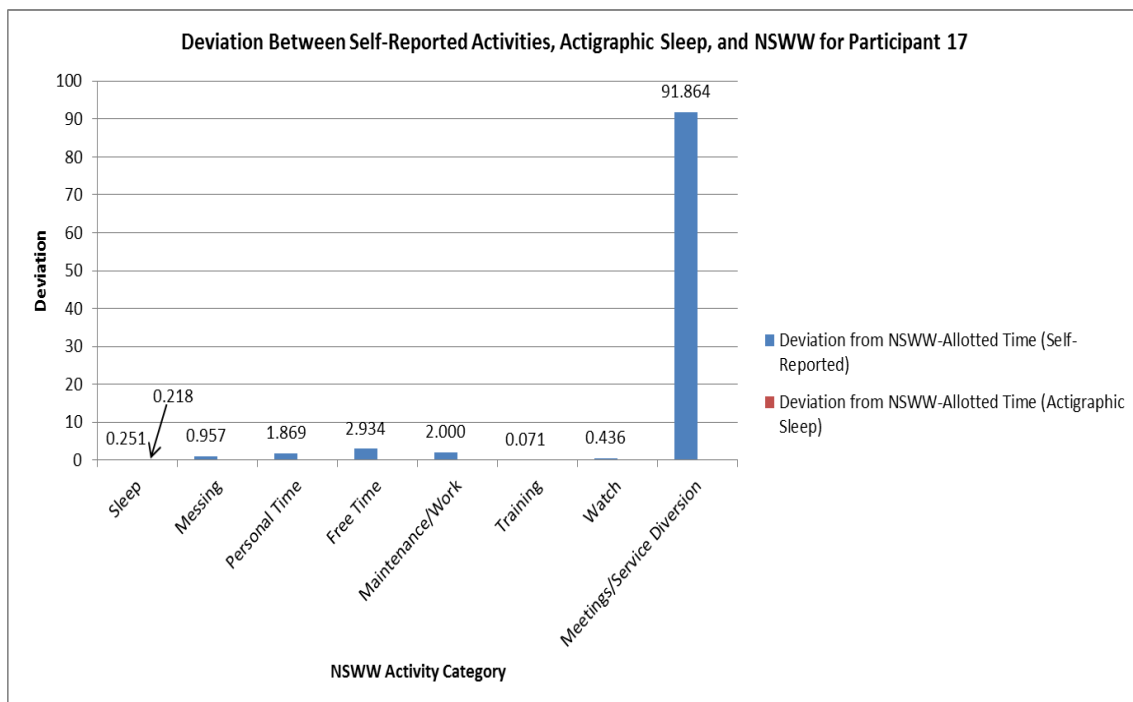Participant 8

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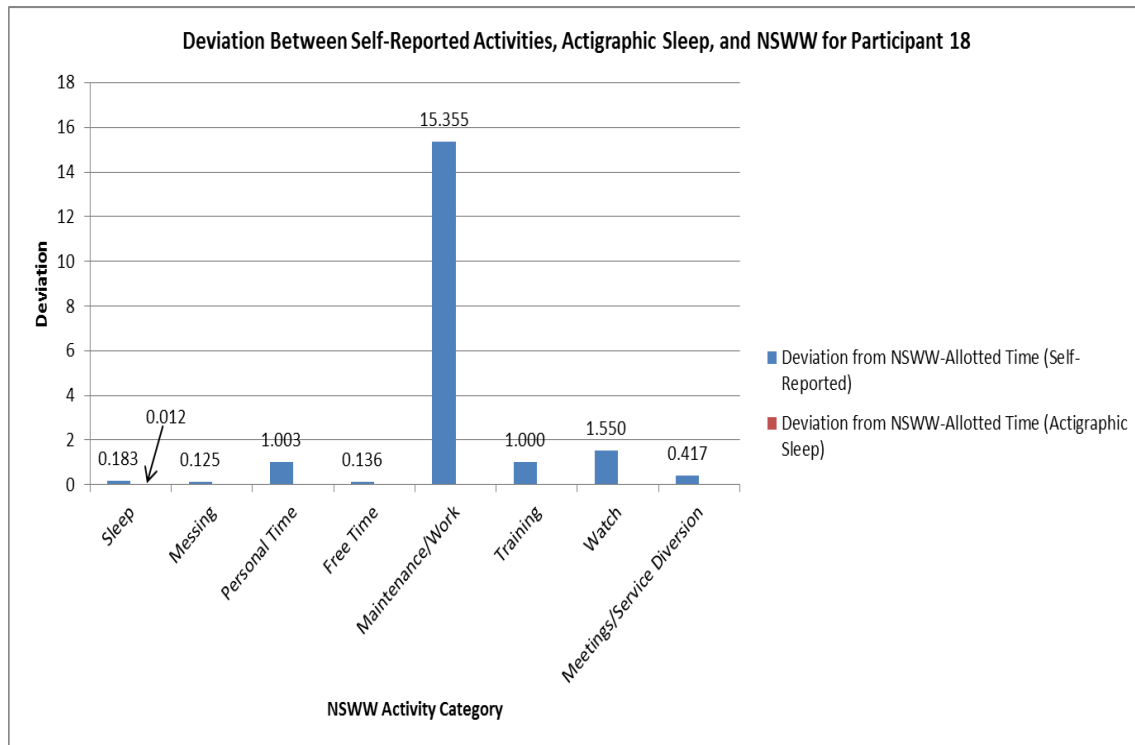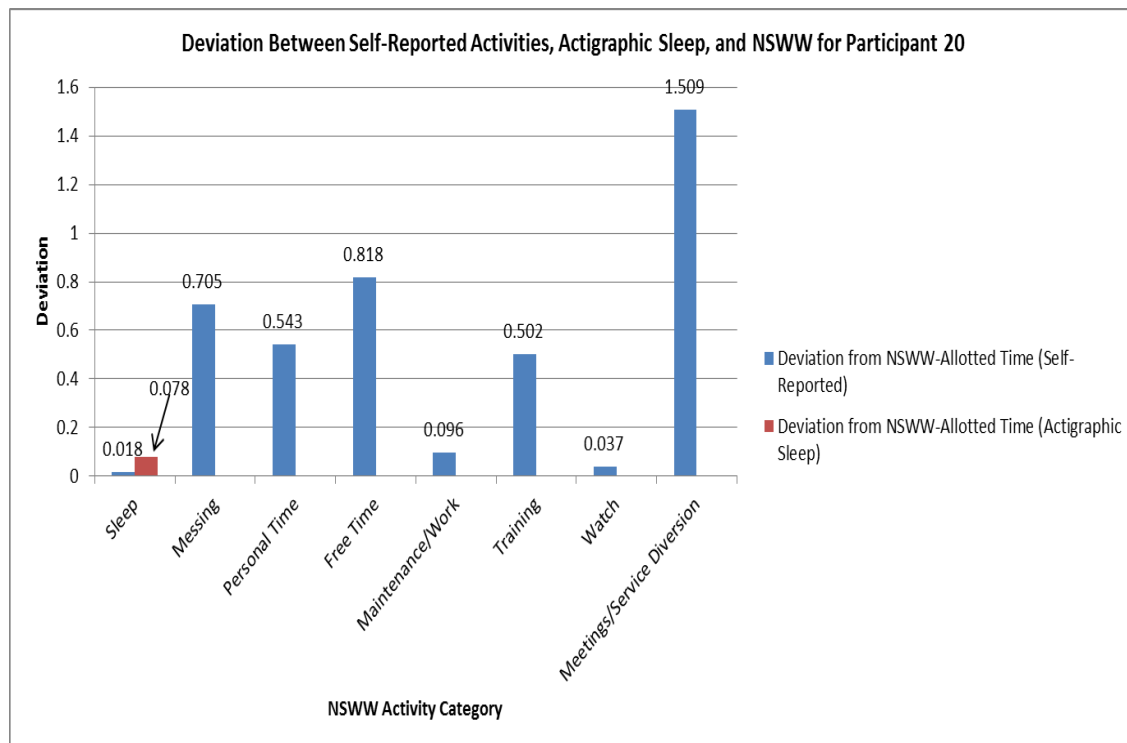

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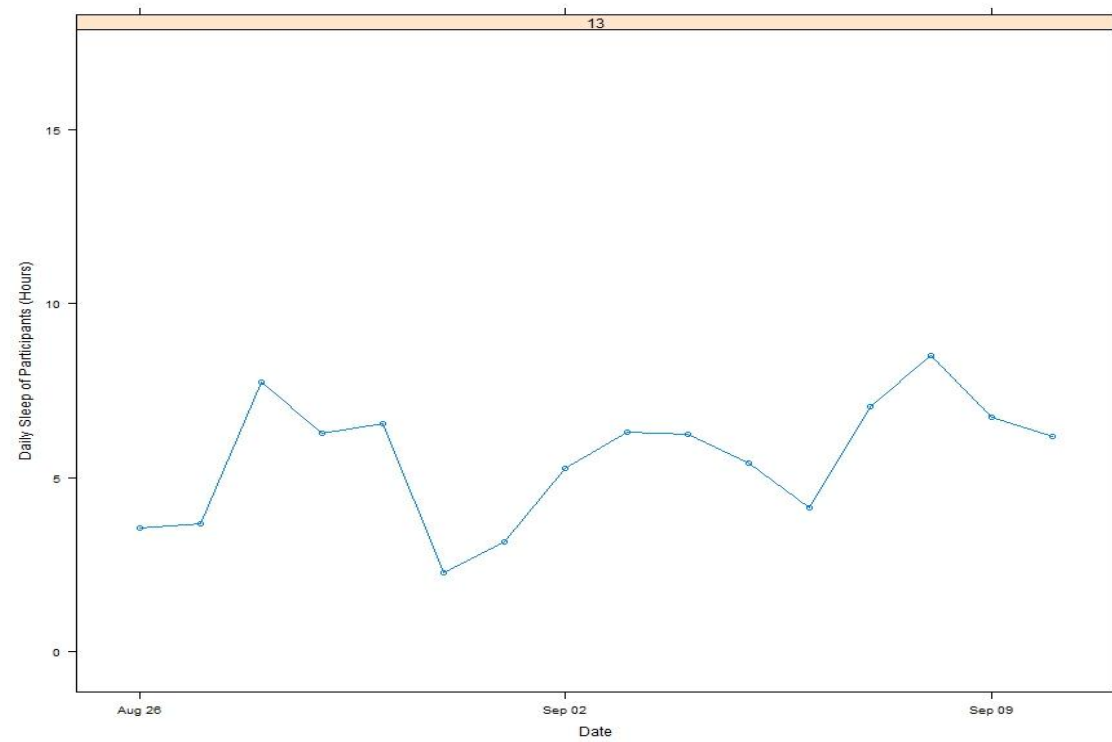
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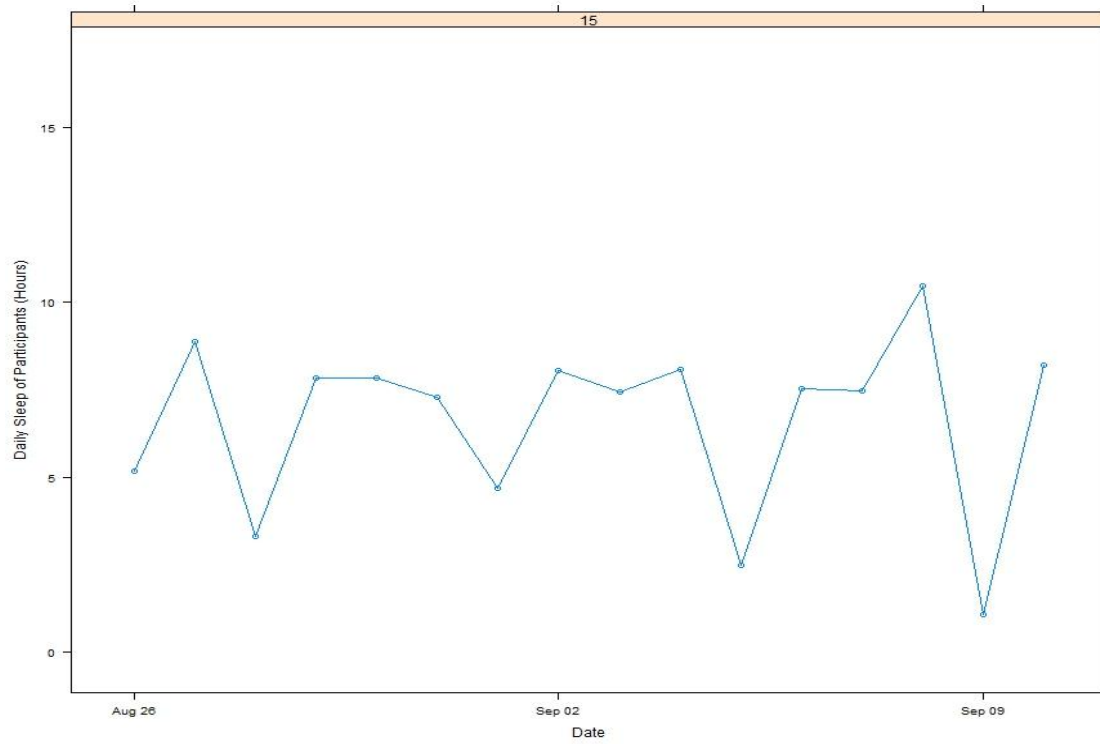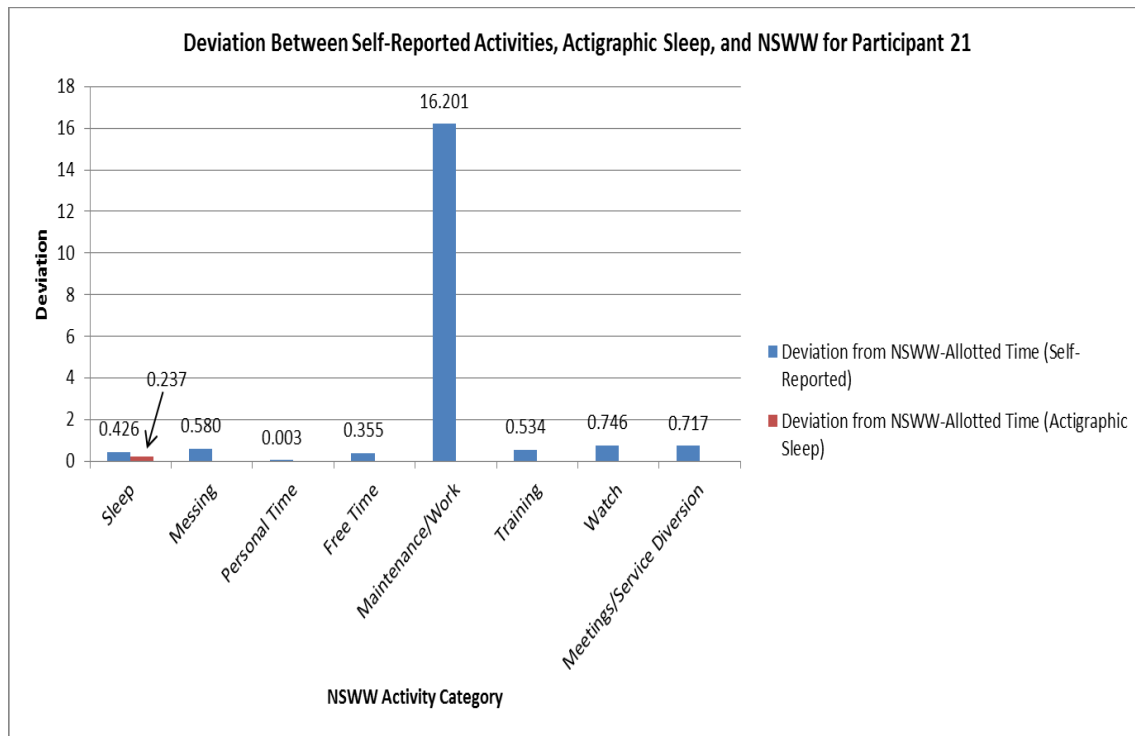

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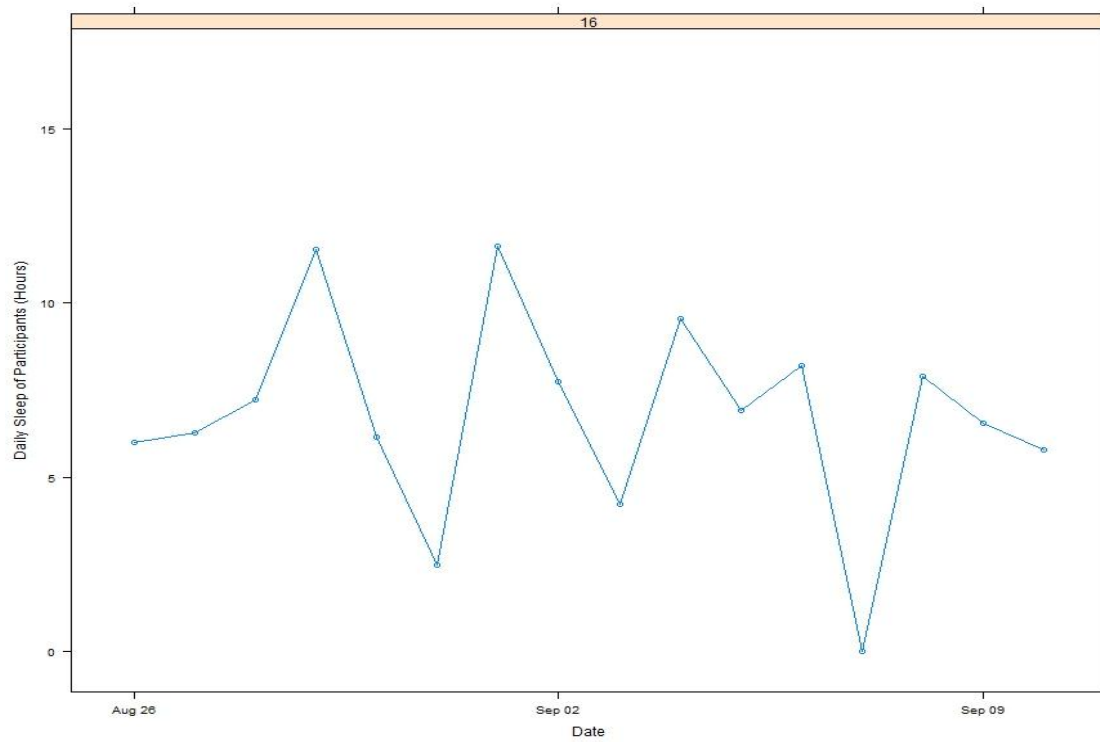
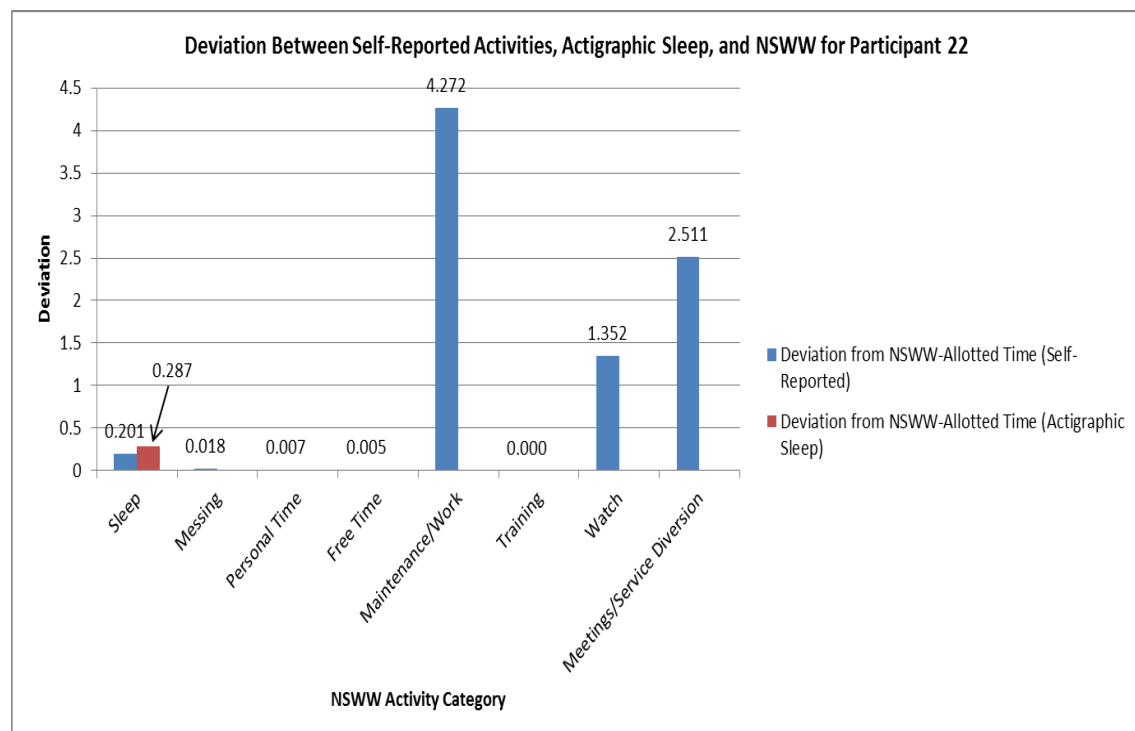Participant 15
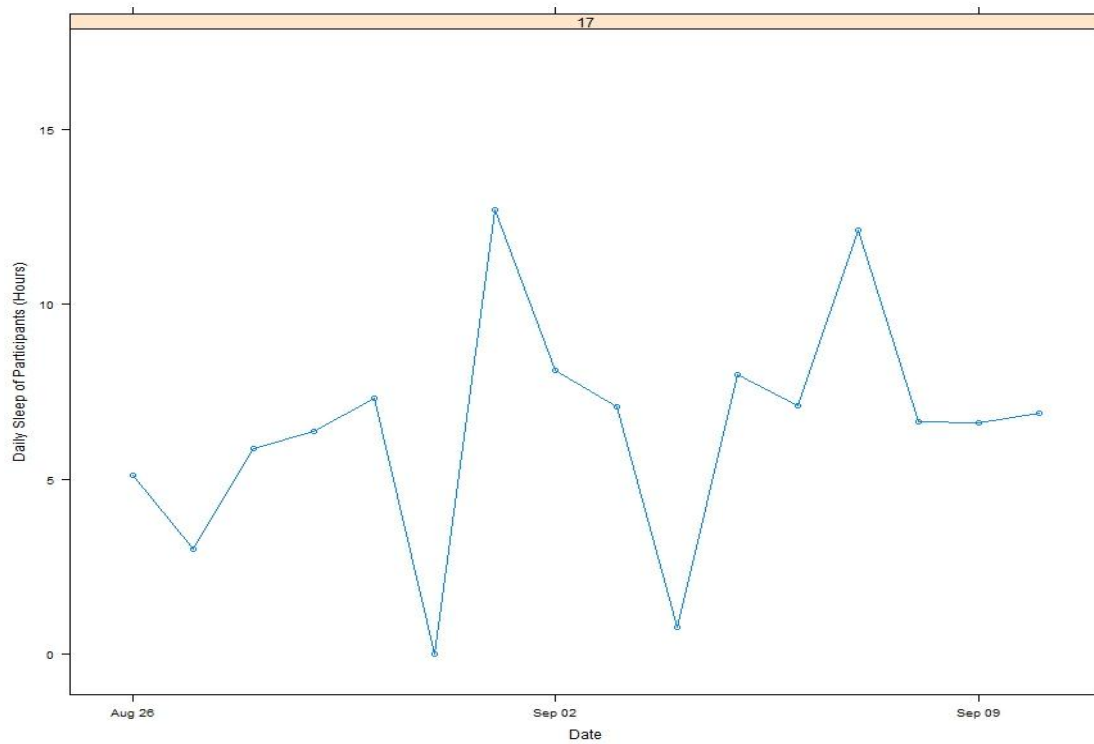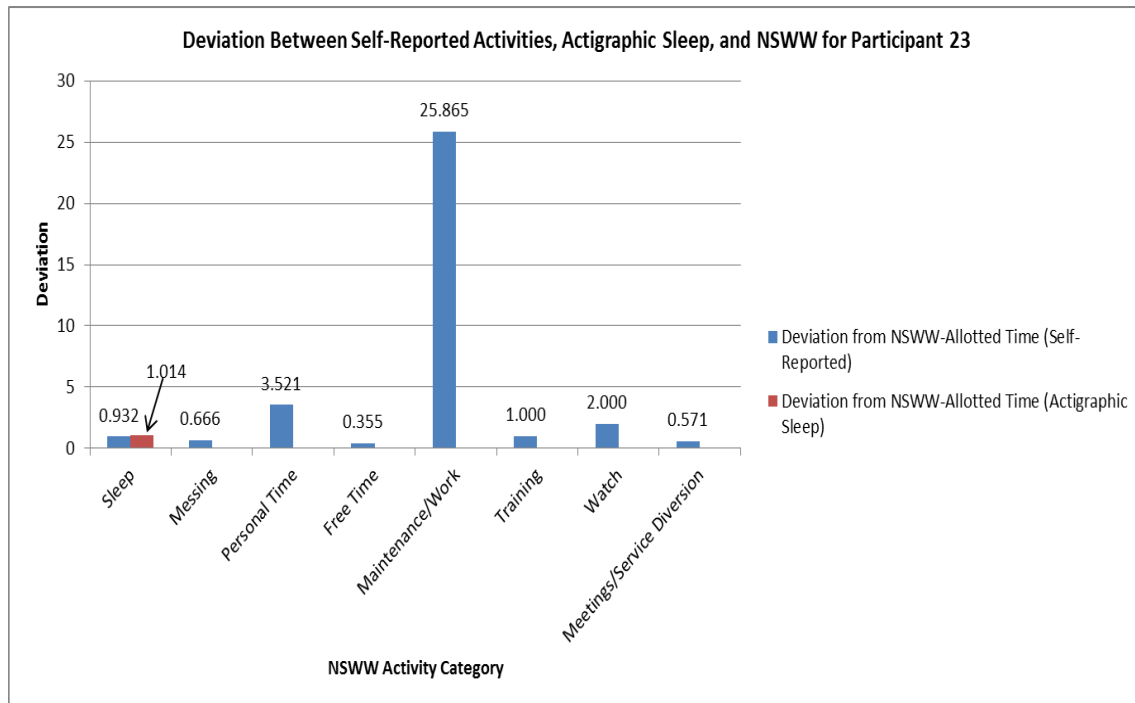

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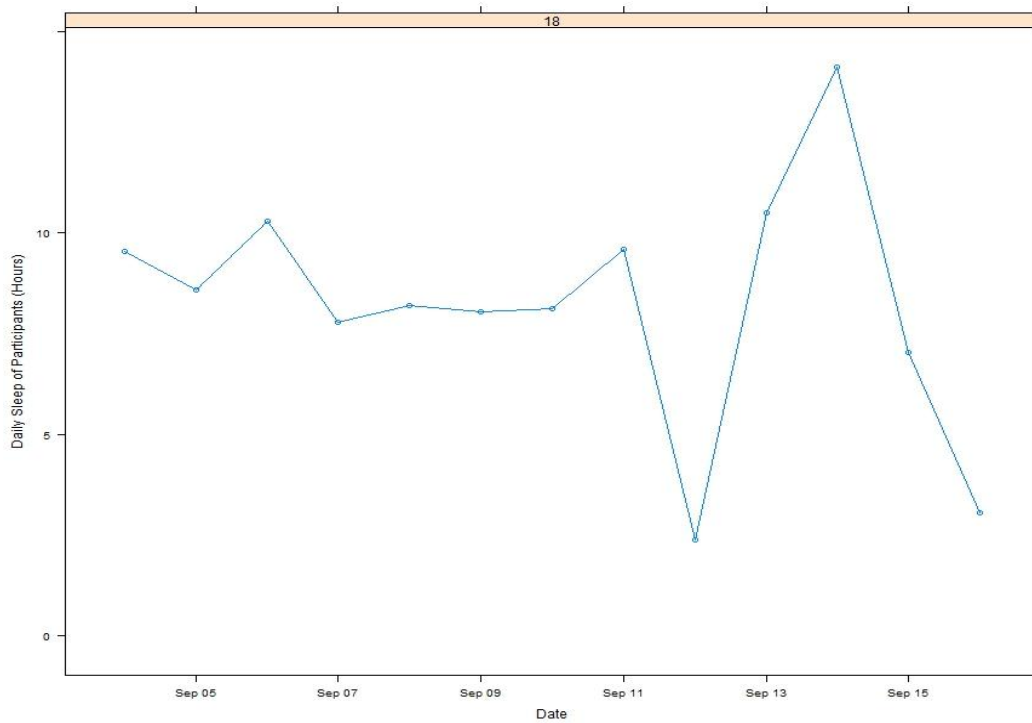
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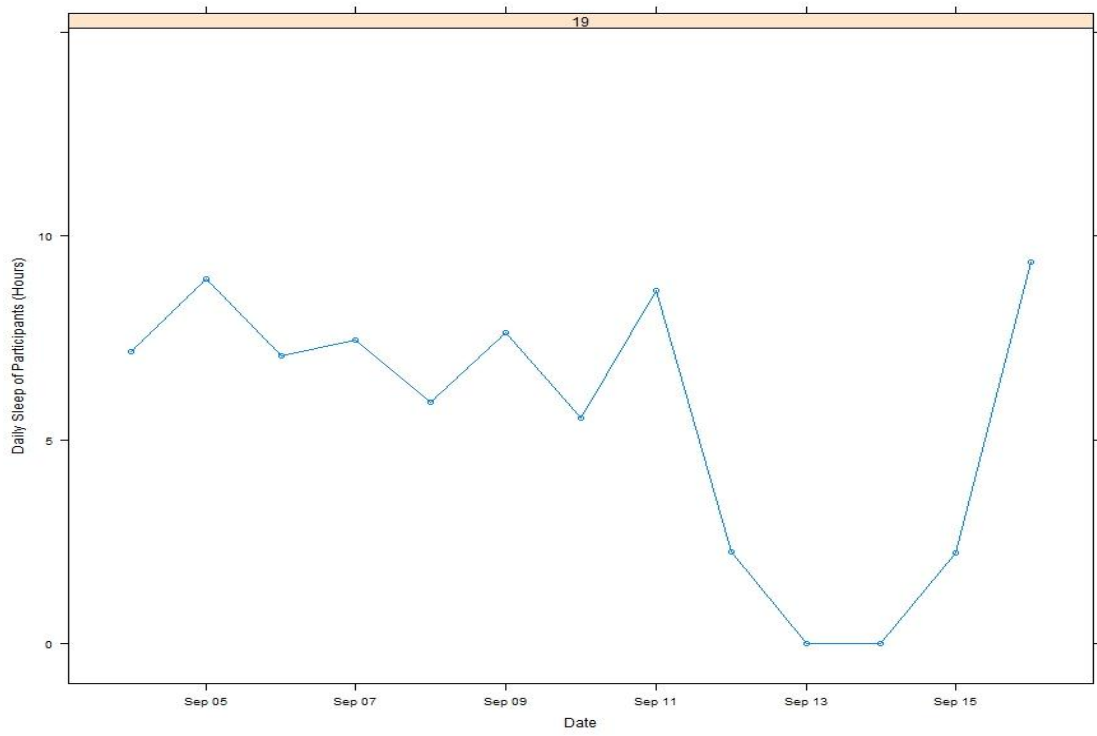
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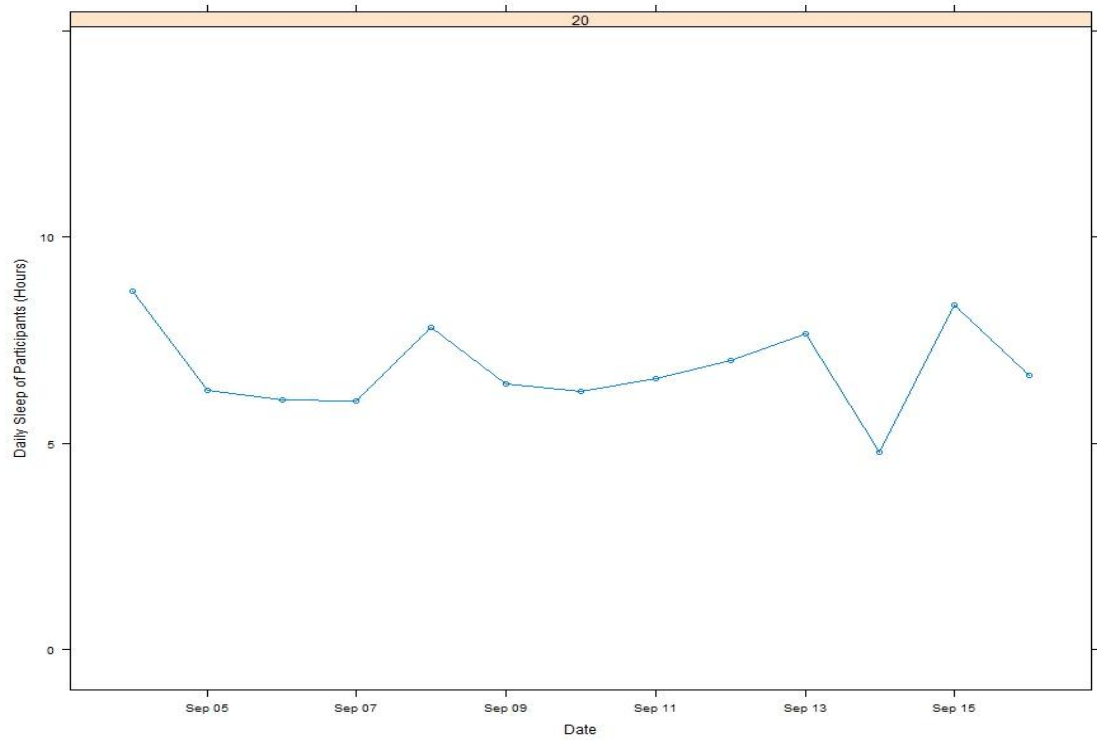
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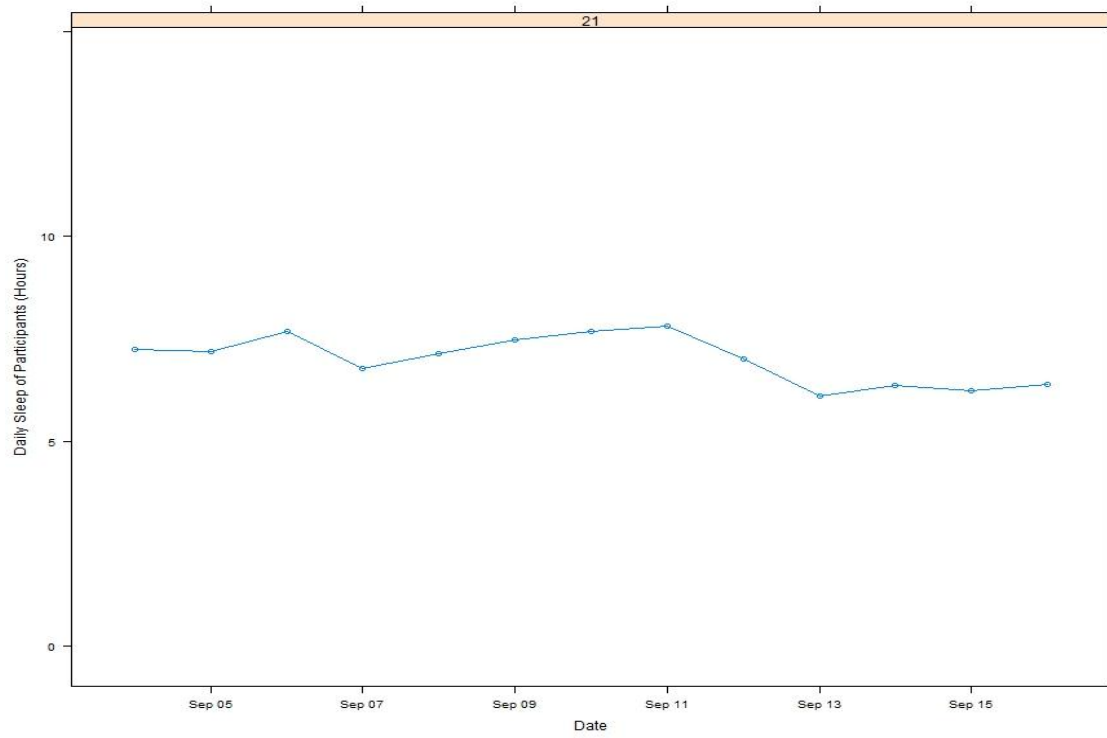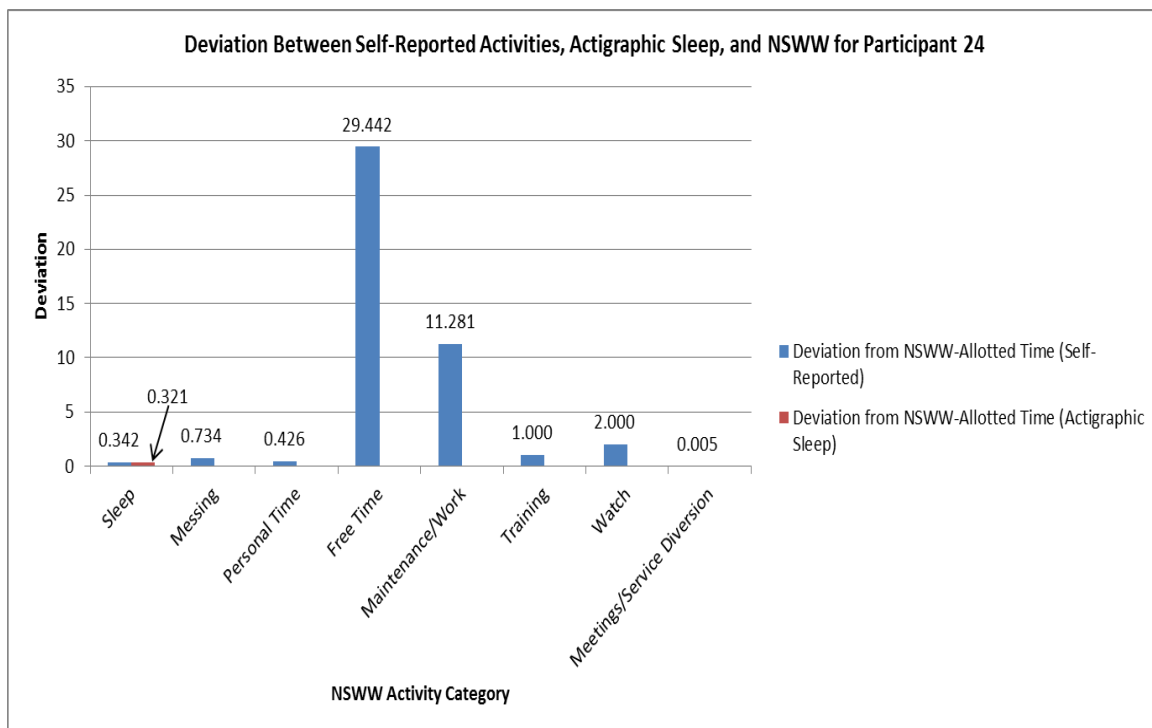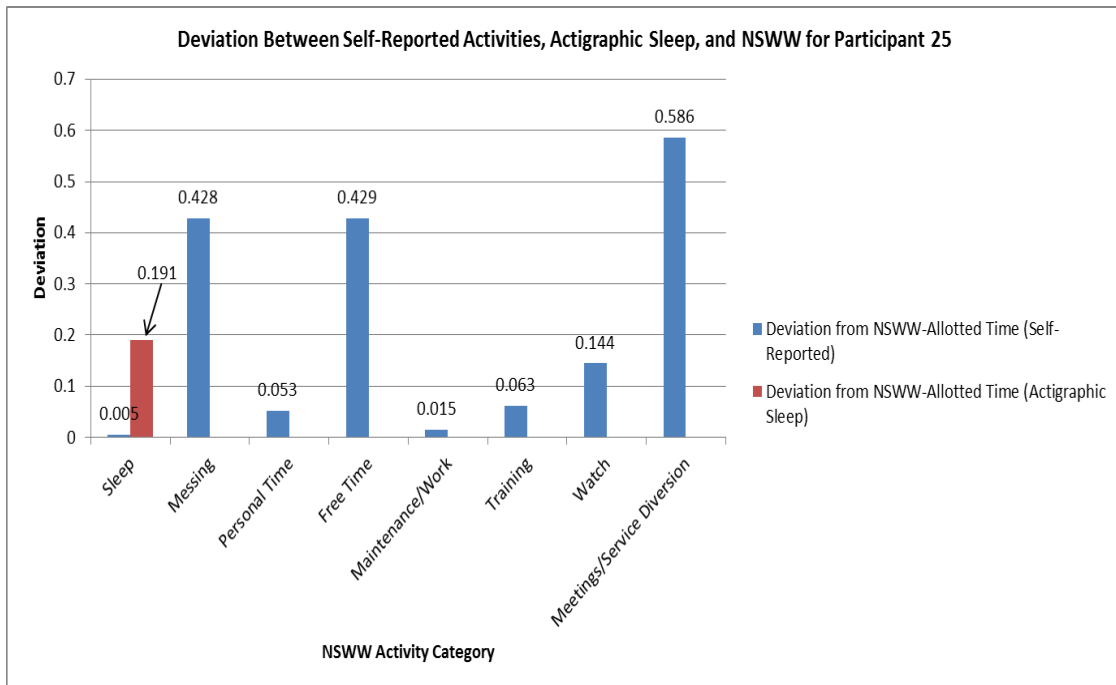
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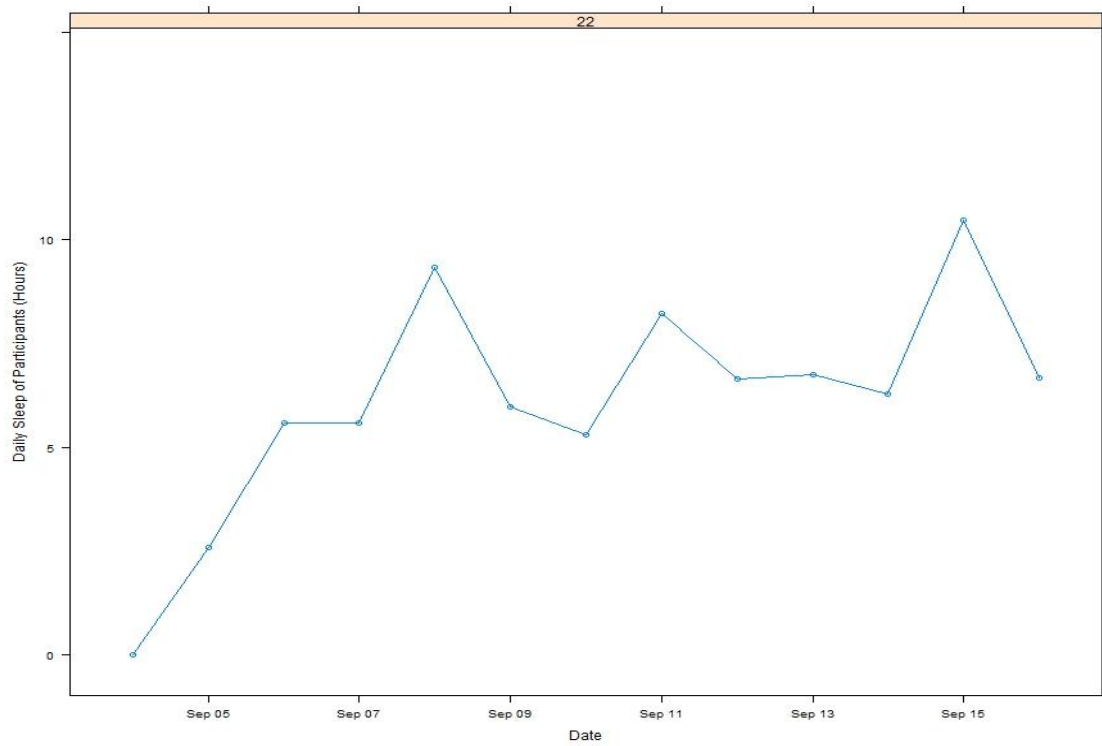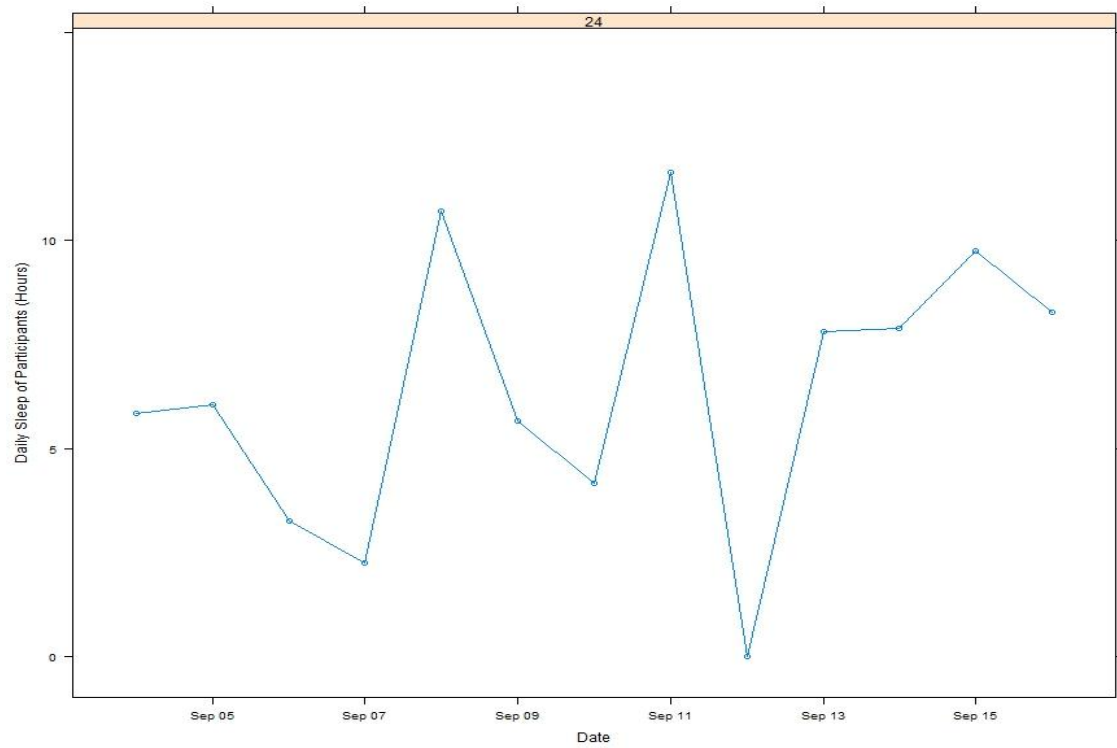
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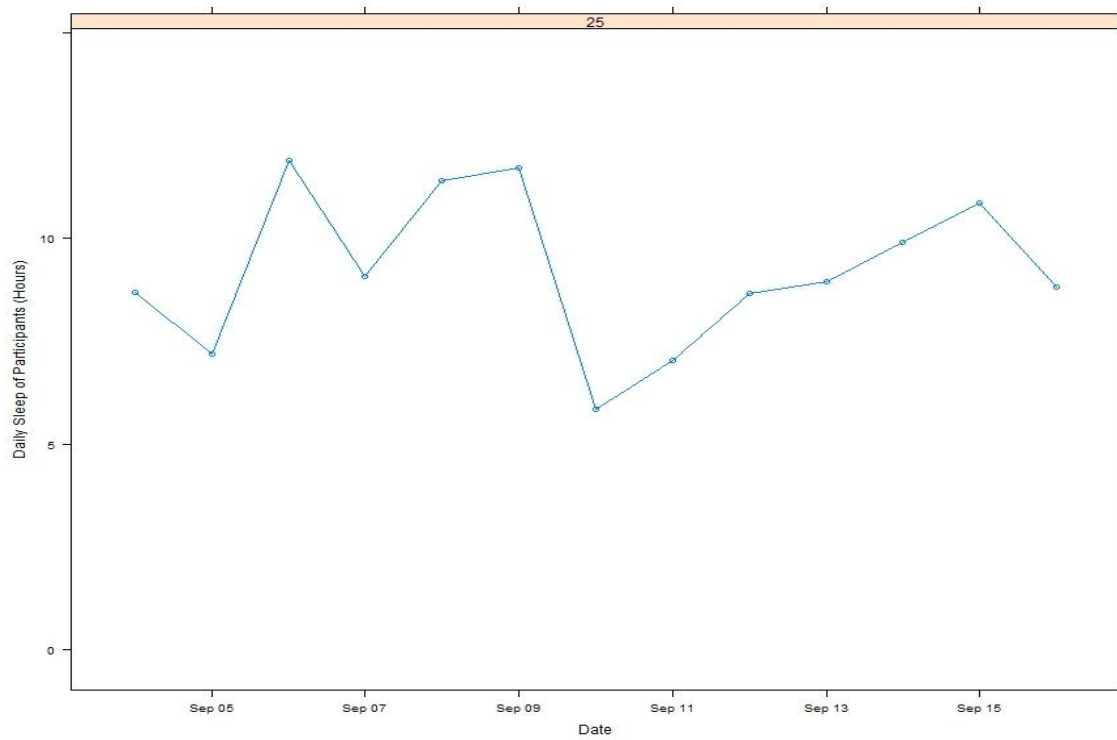
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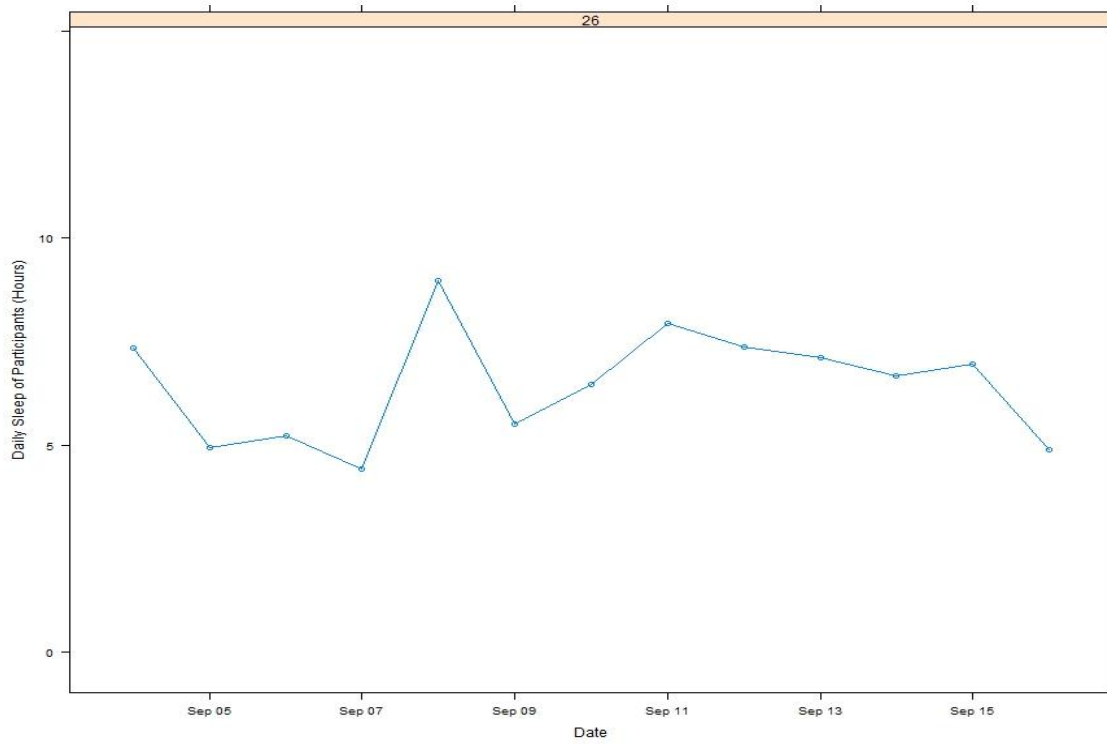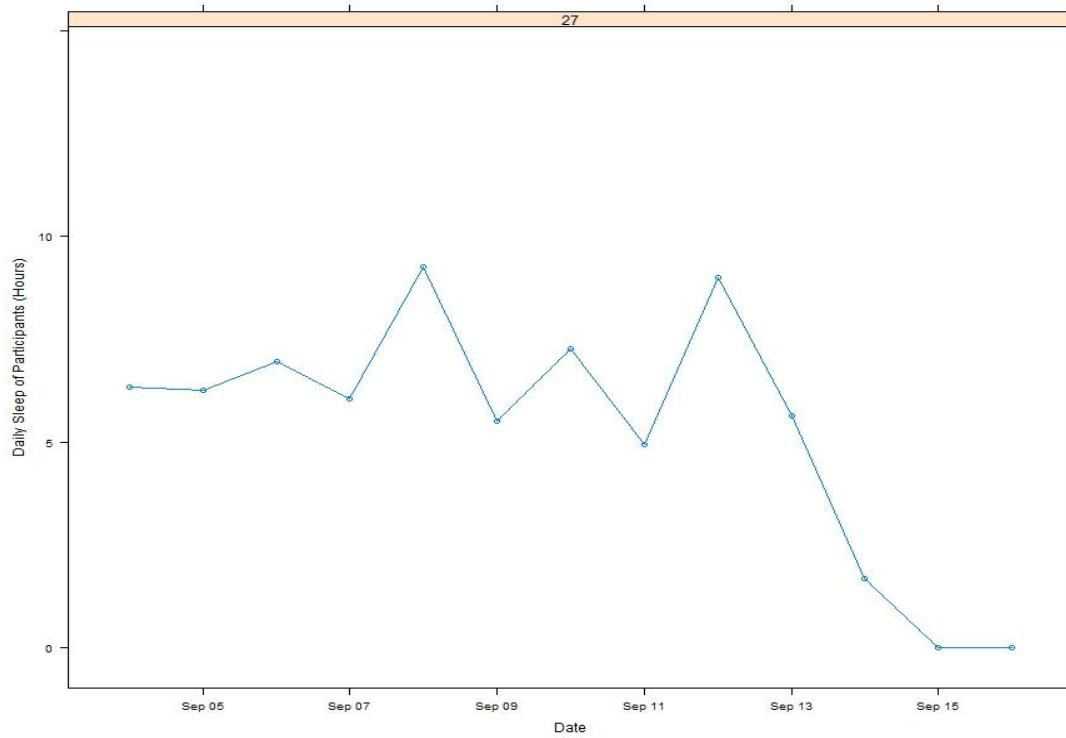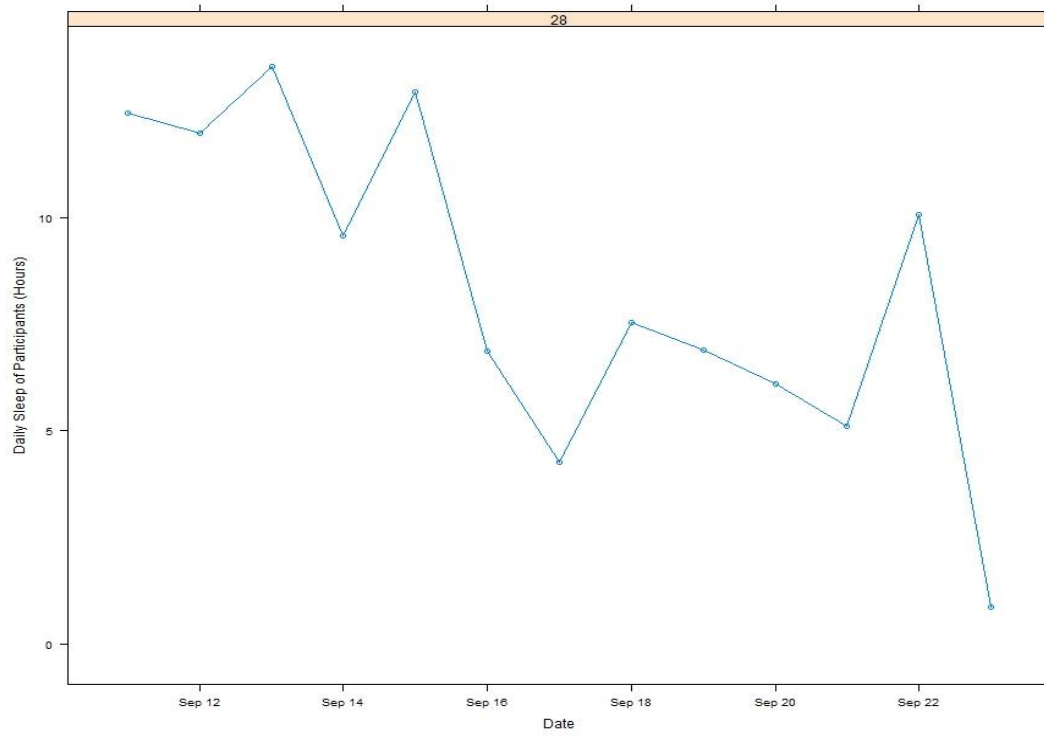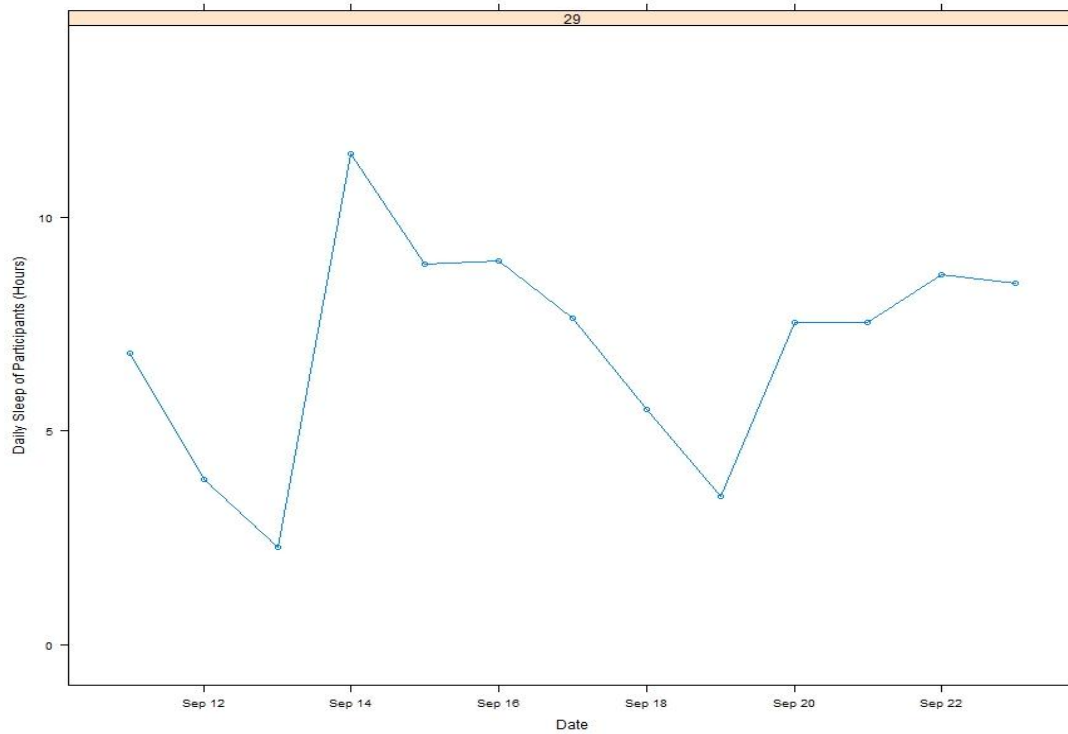
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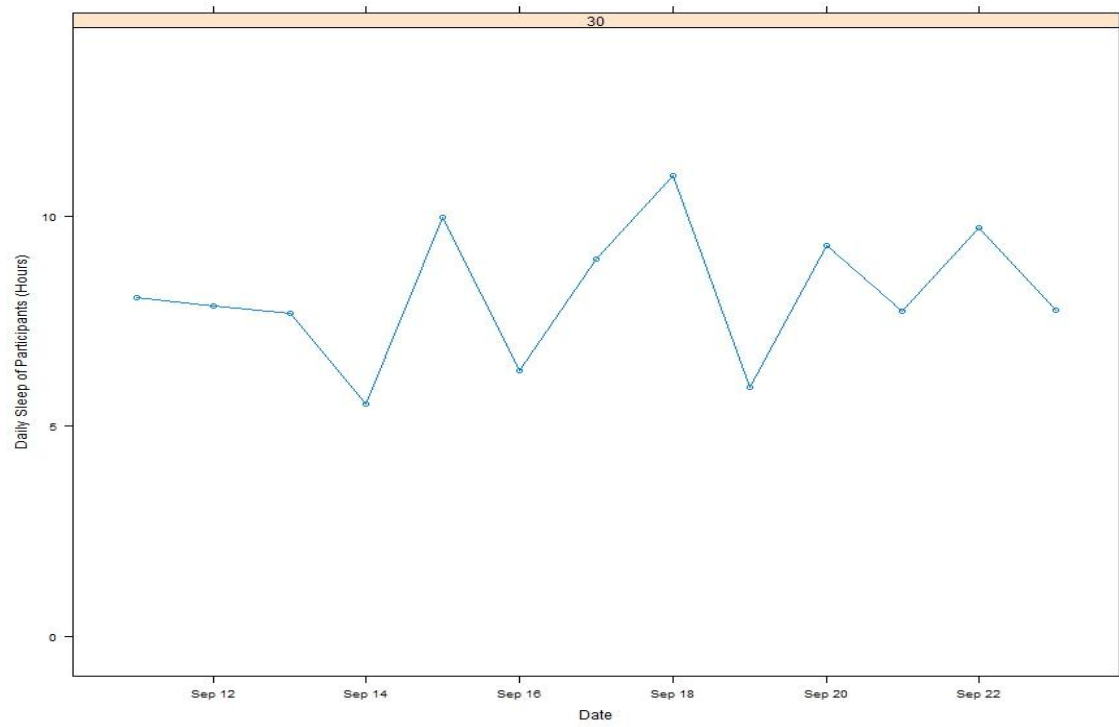
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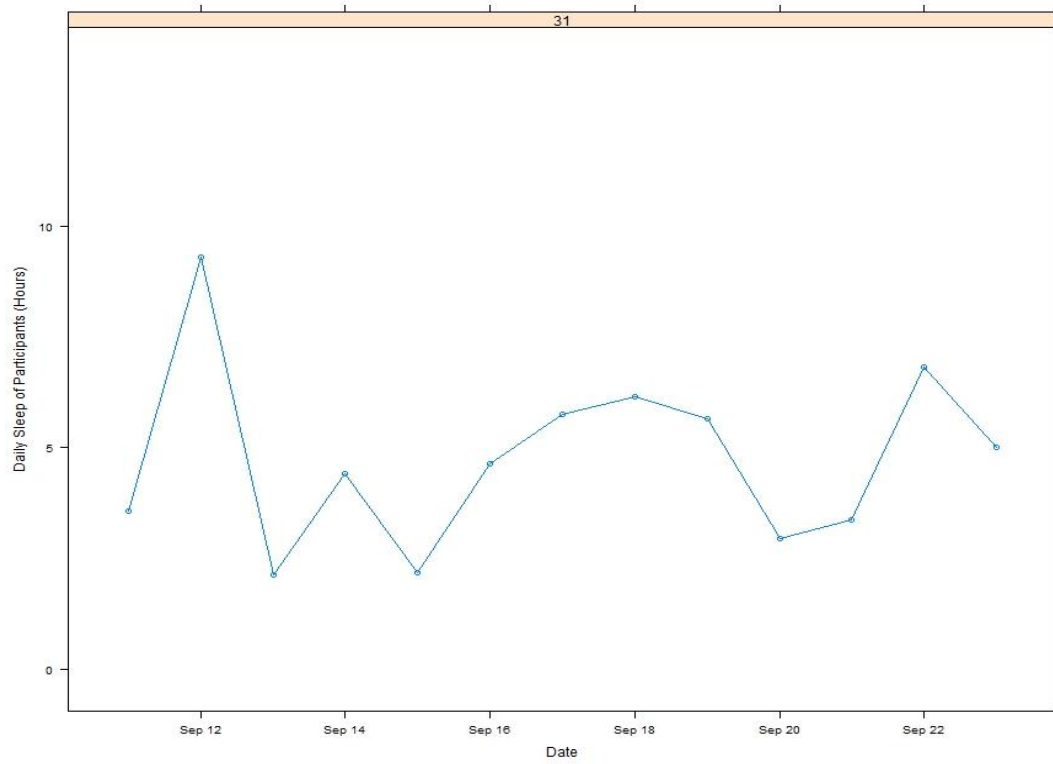
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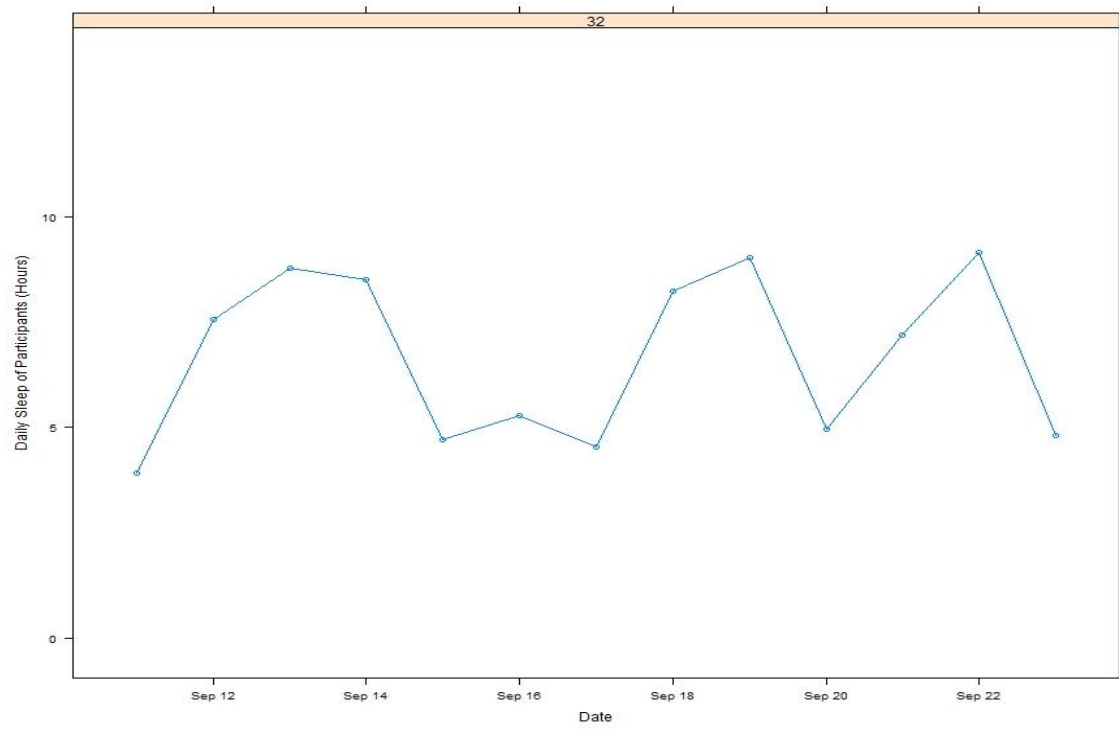
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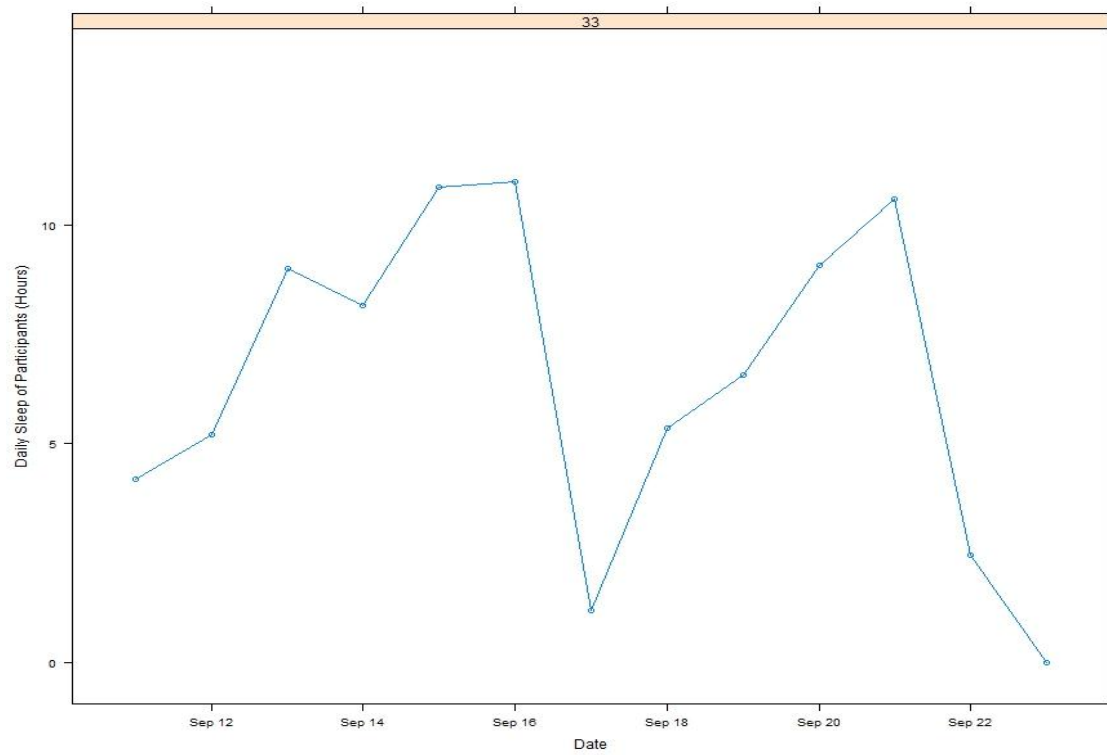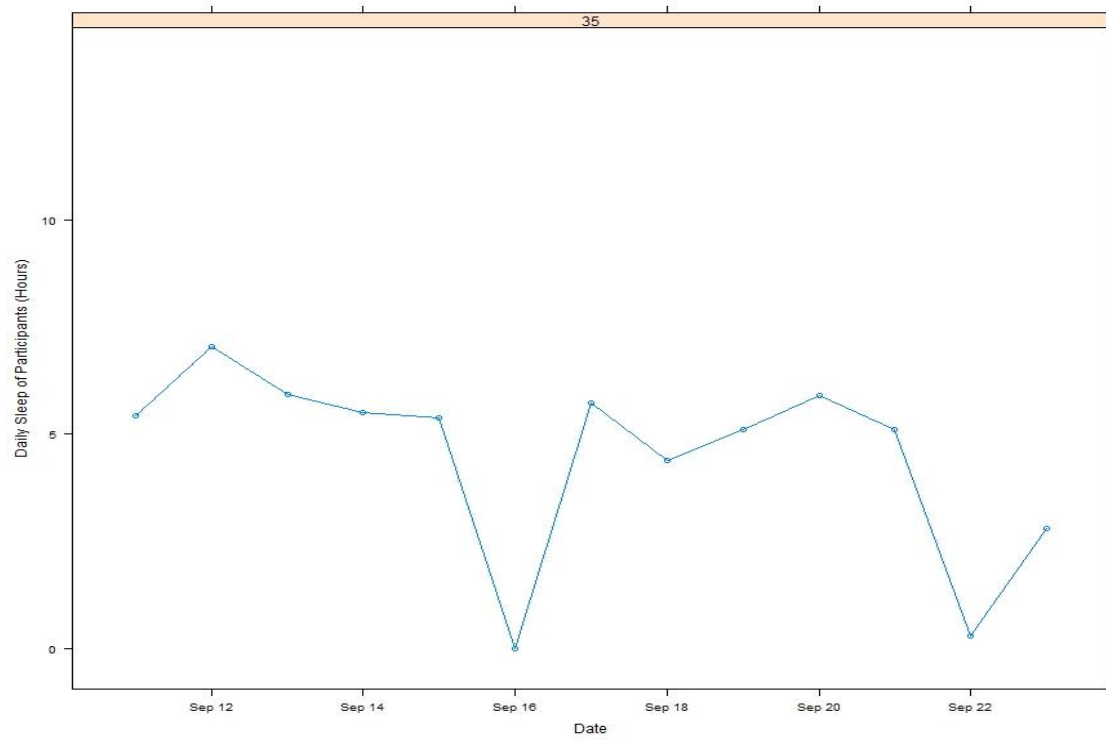
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APPENDIX G.   INDIVIDUAL PARTICIPANT ACTIGRAPHIC SLEEP AND SELF-REPORTED ACTIVITIES VS. THE NSWW
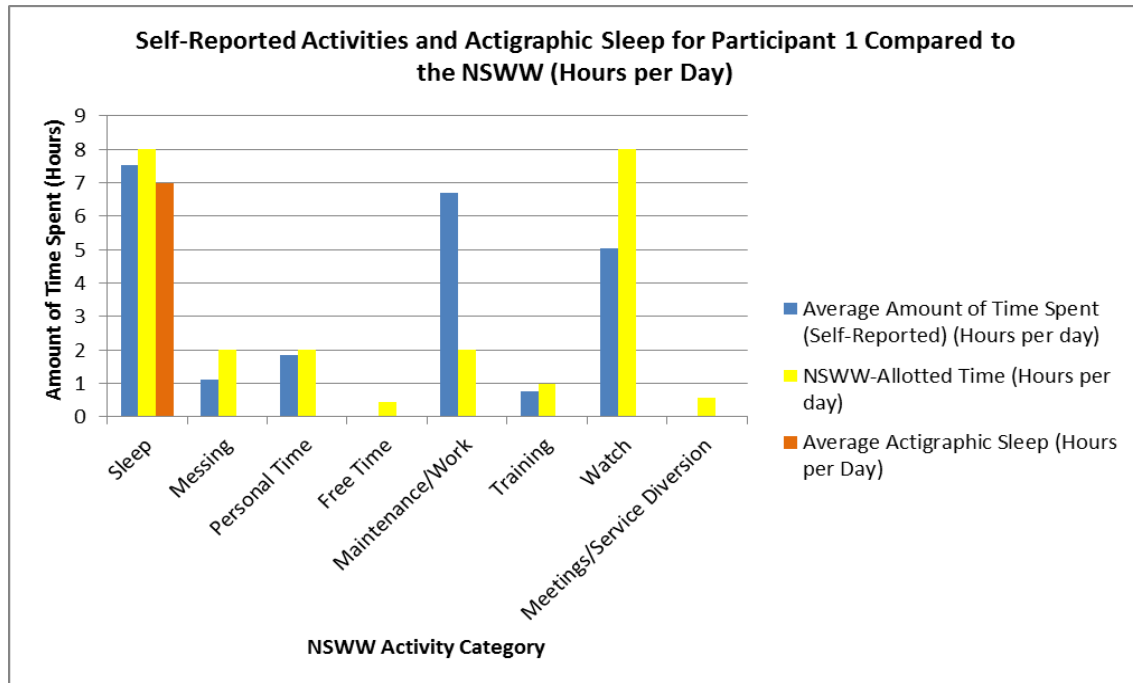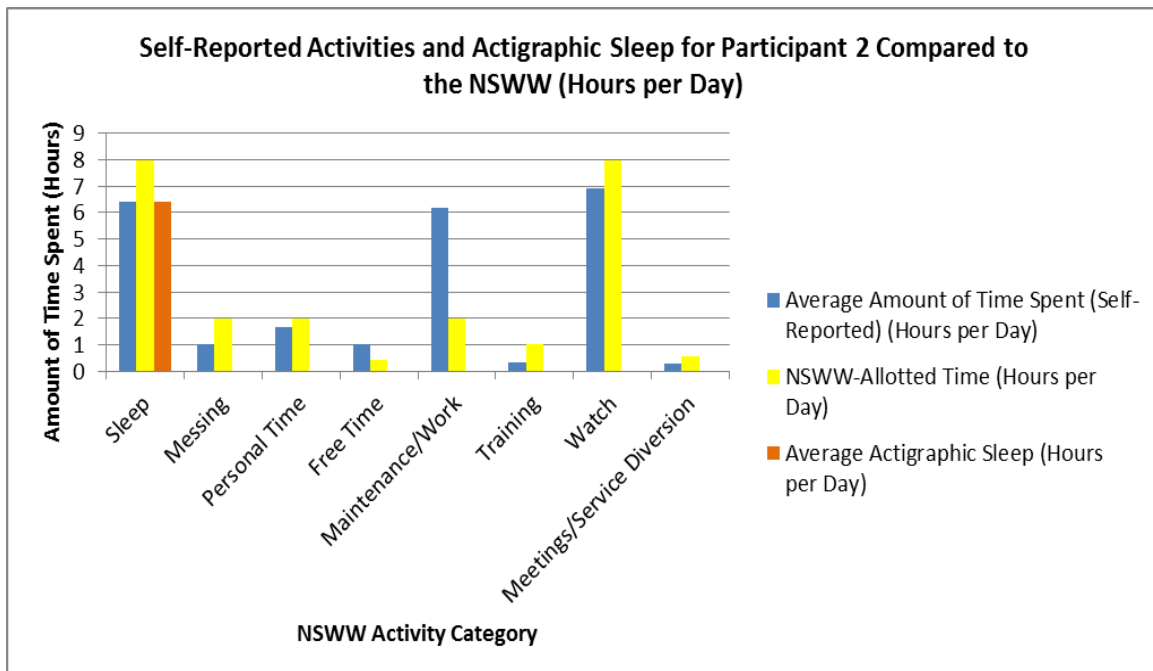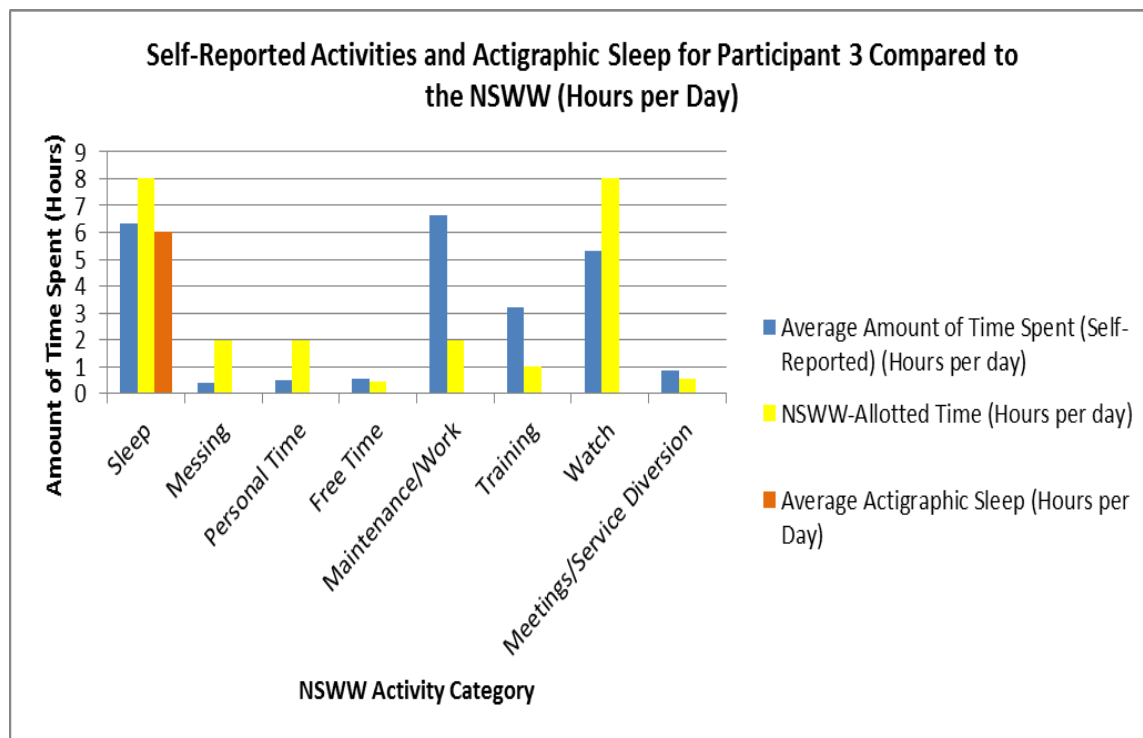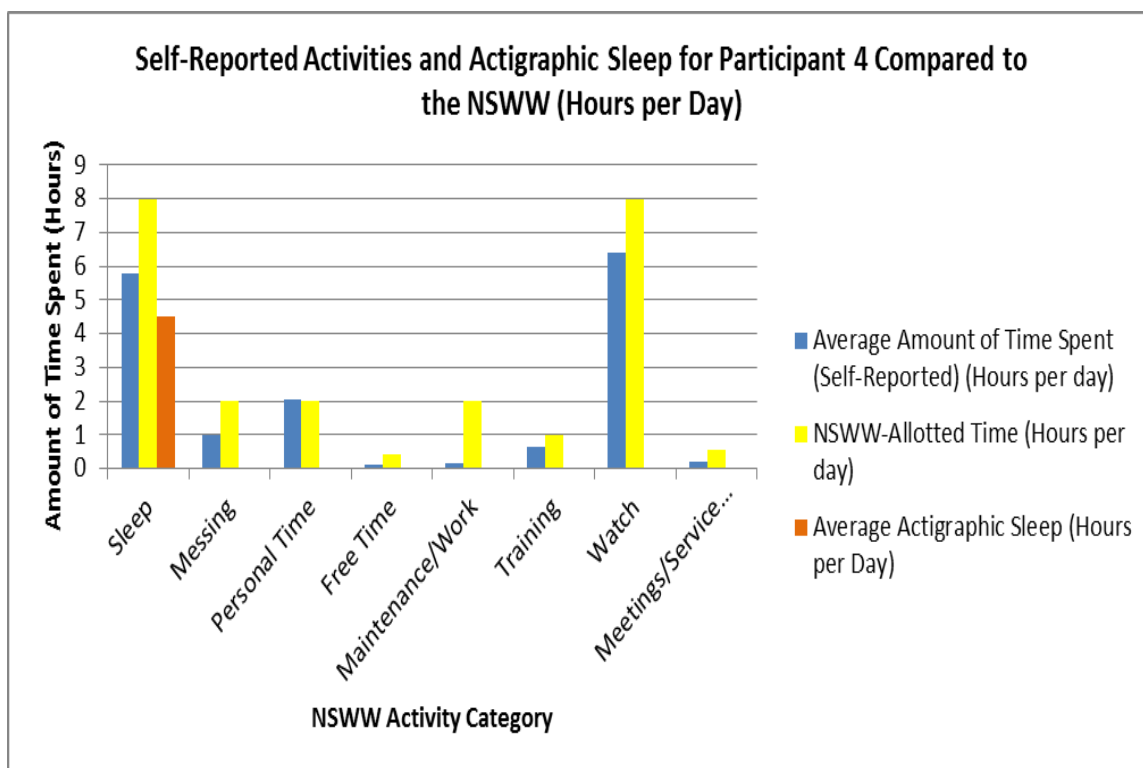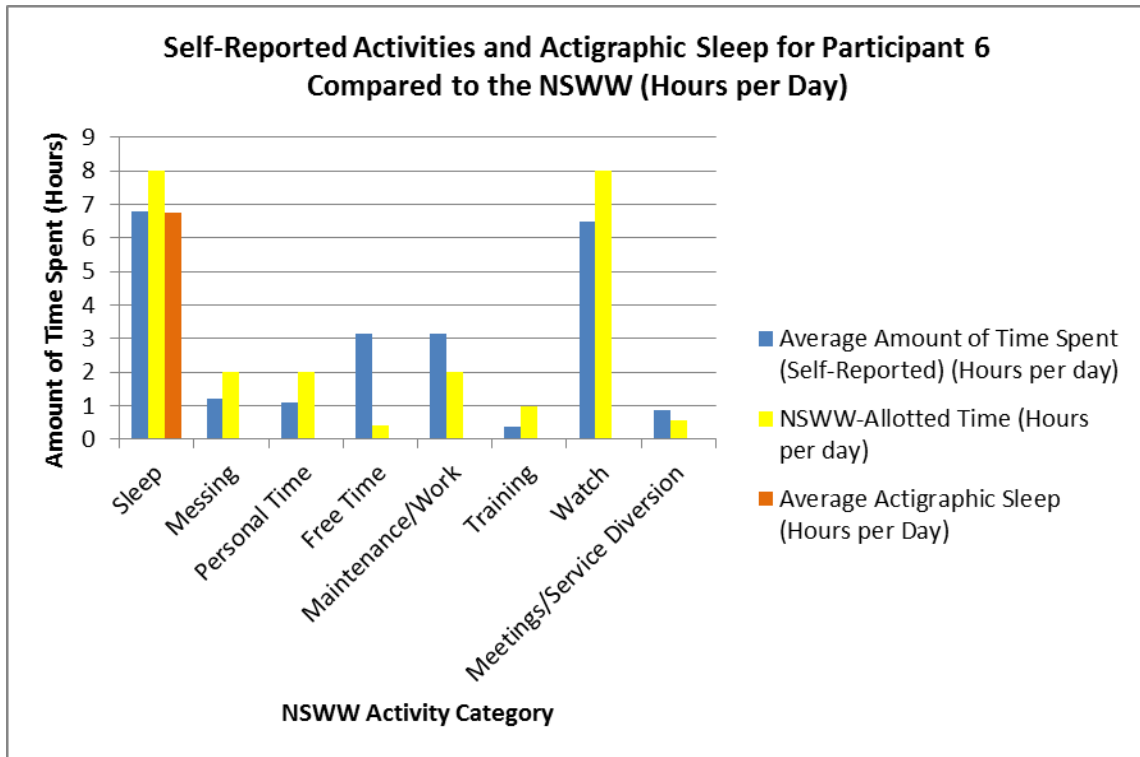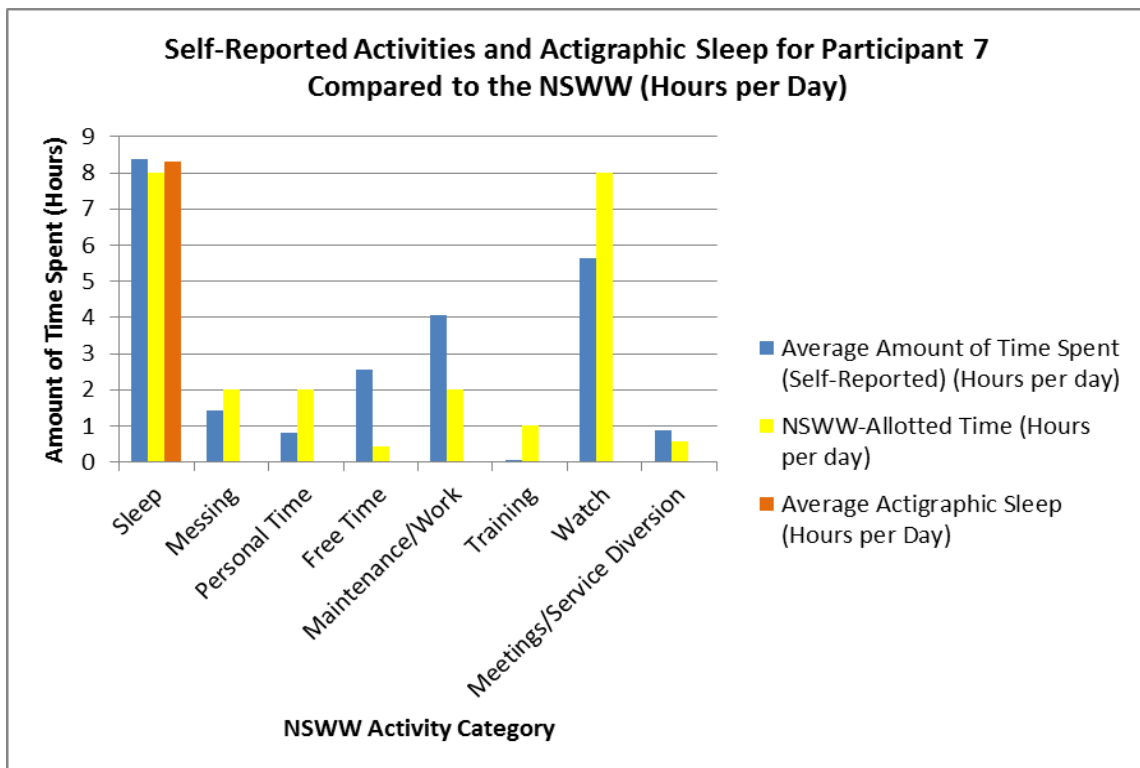
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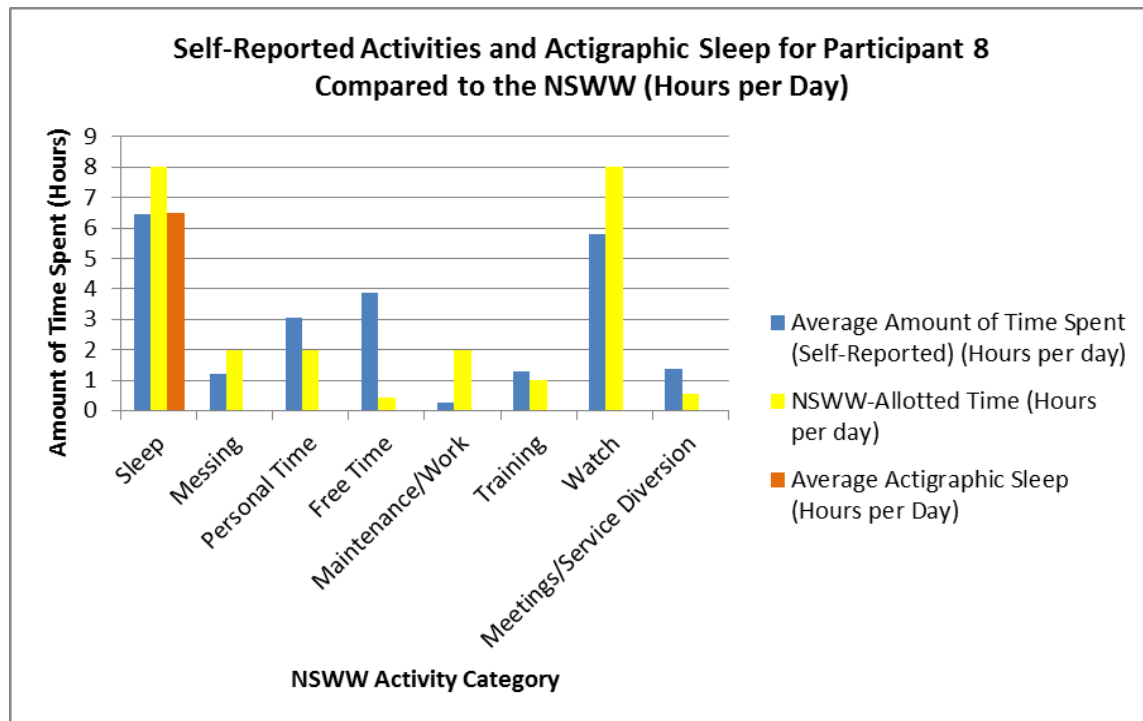
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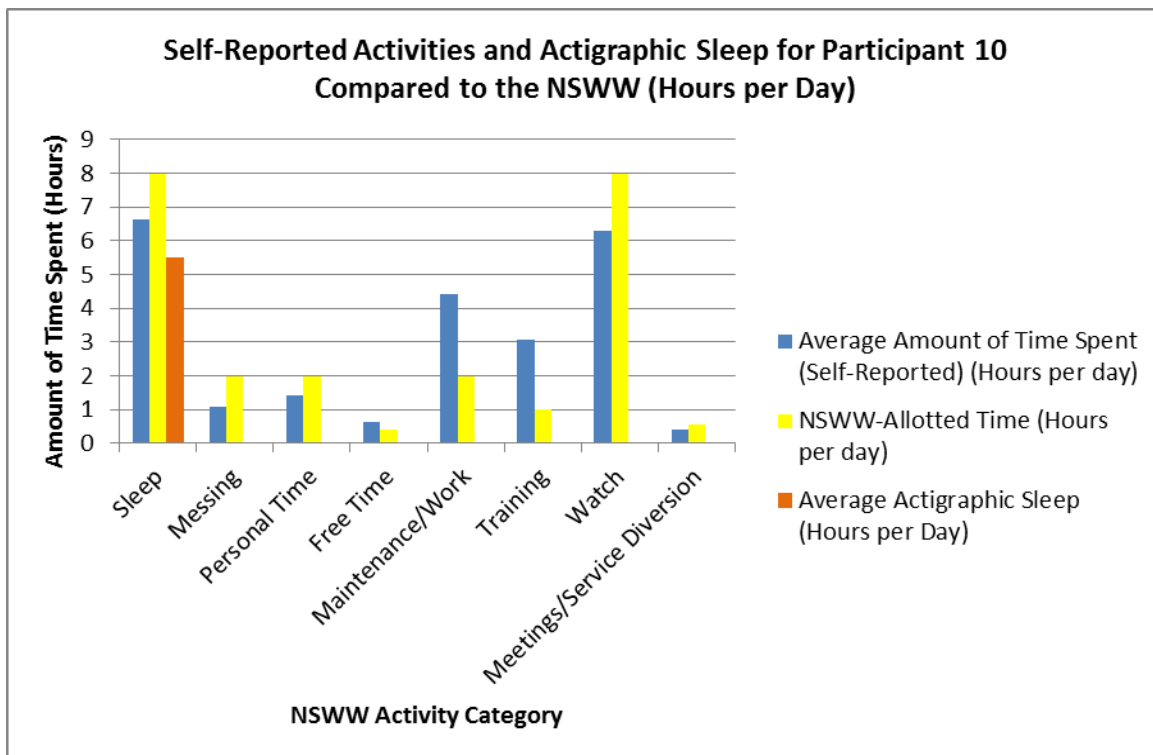
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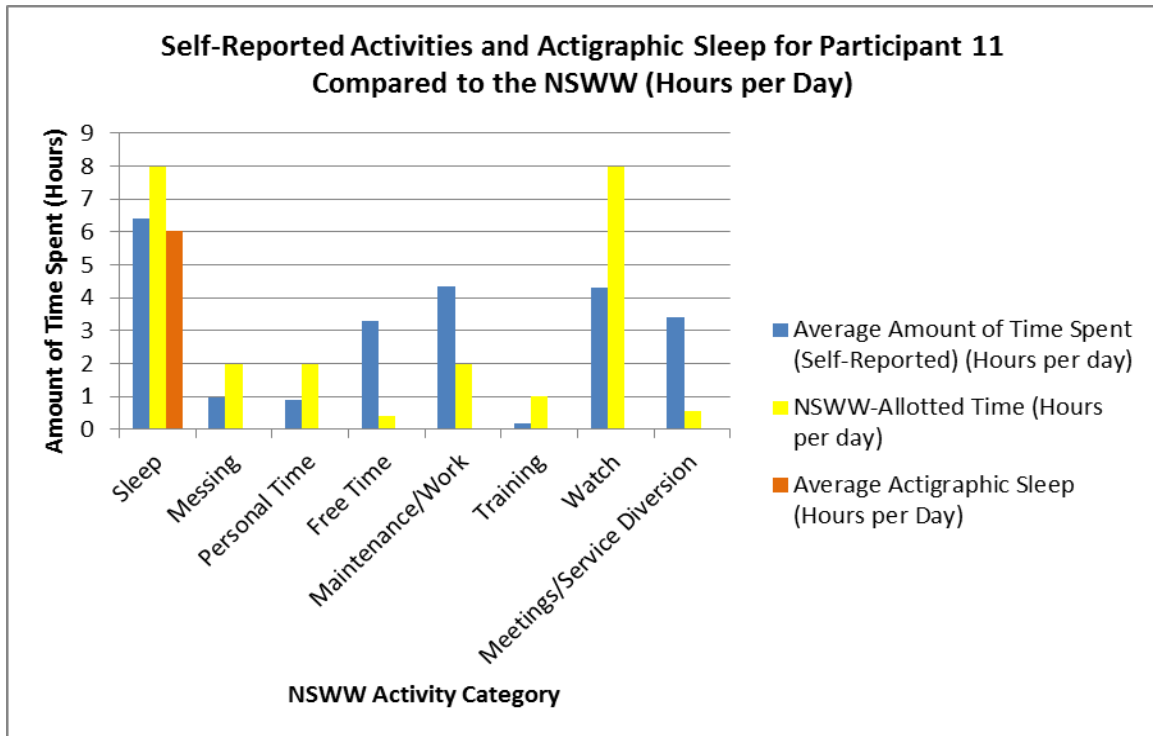
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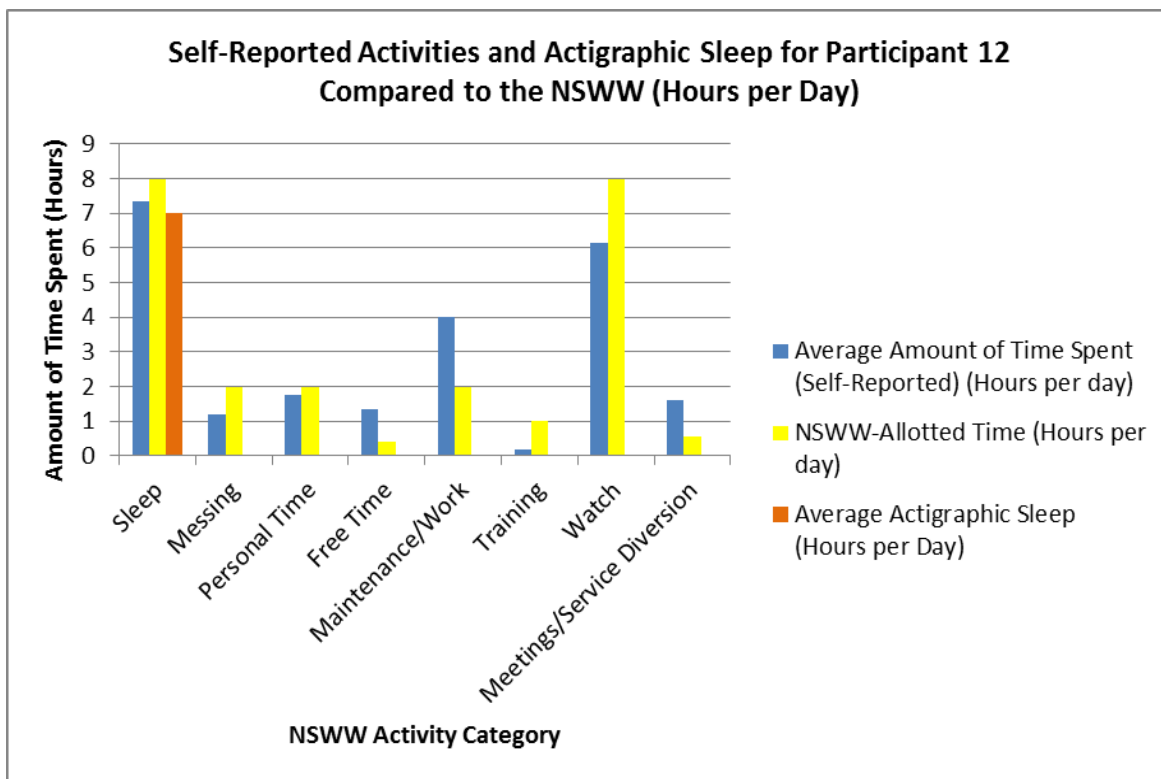
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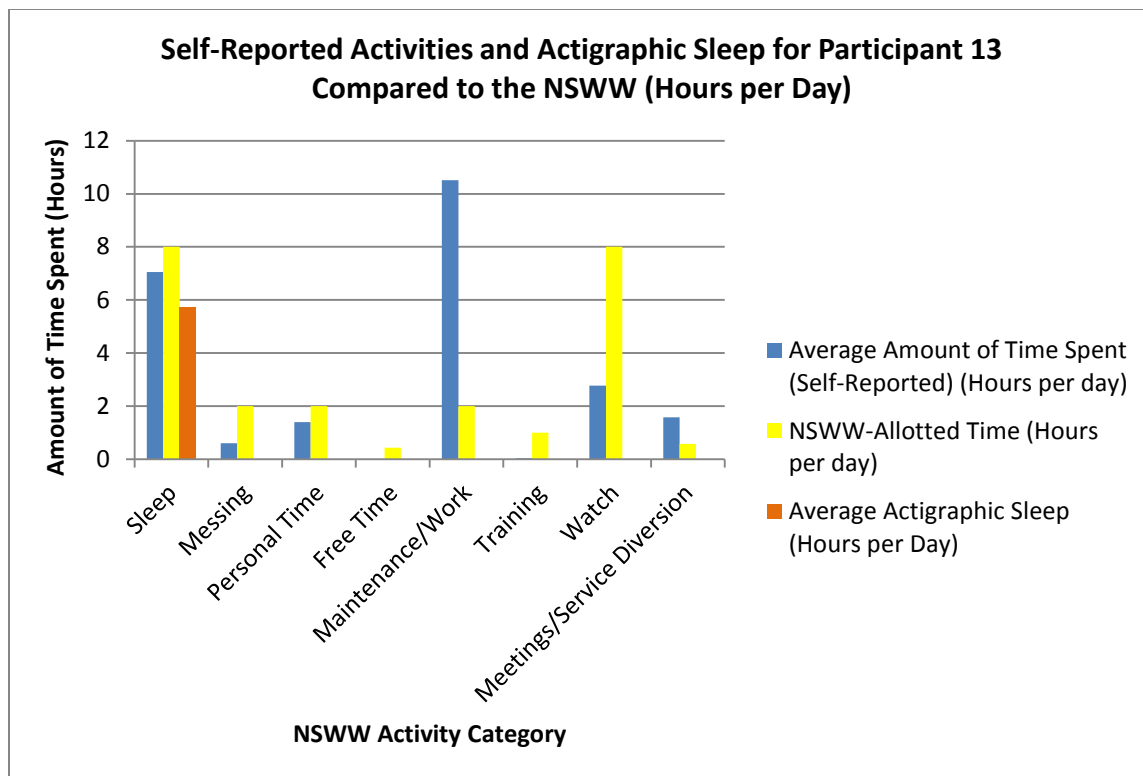
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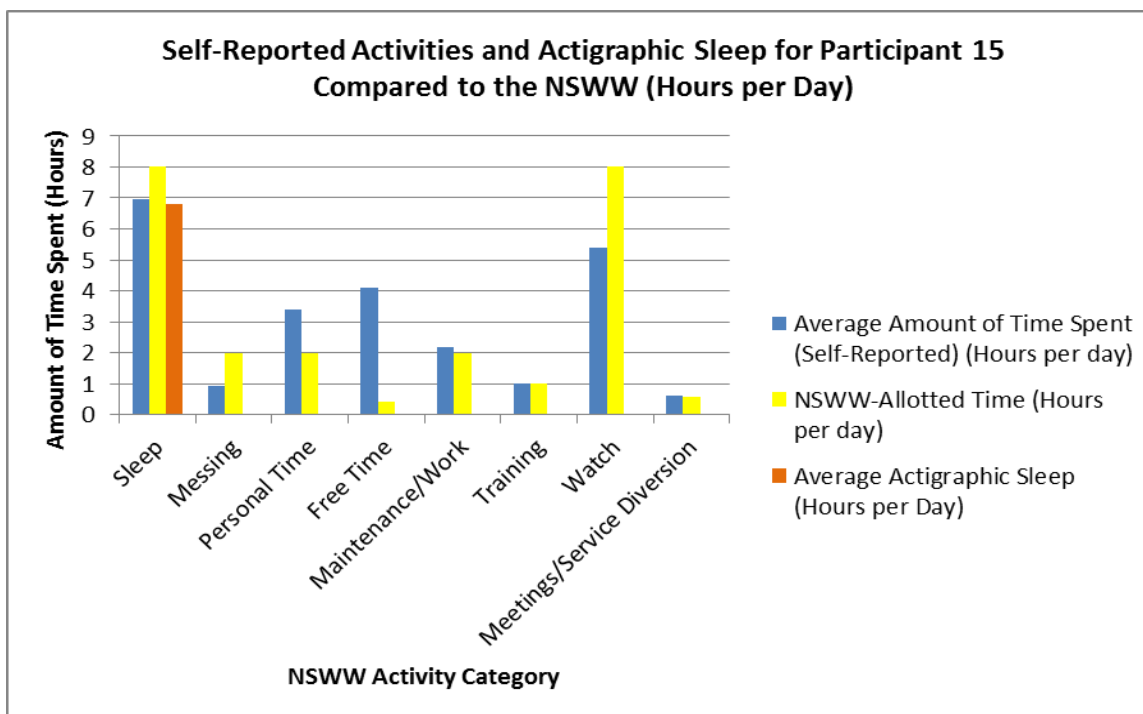
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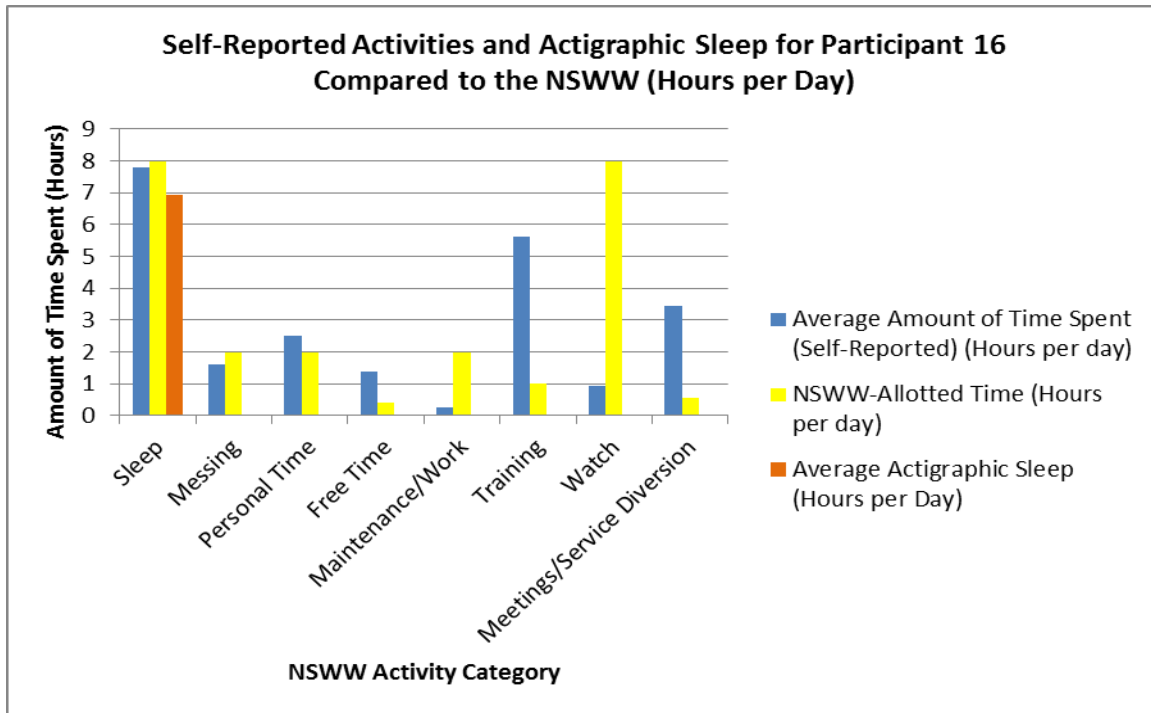
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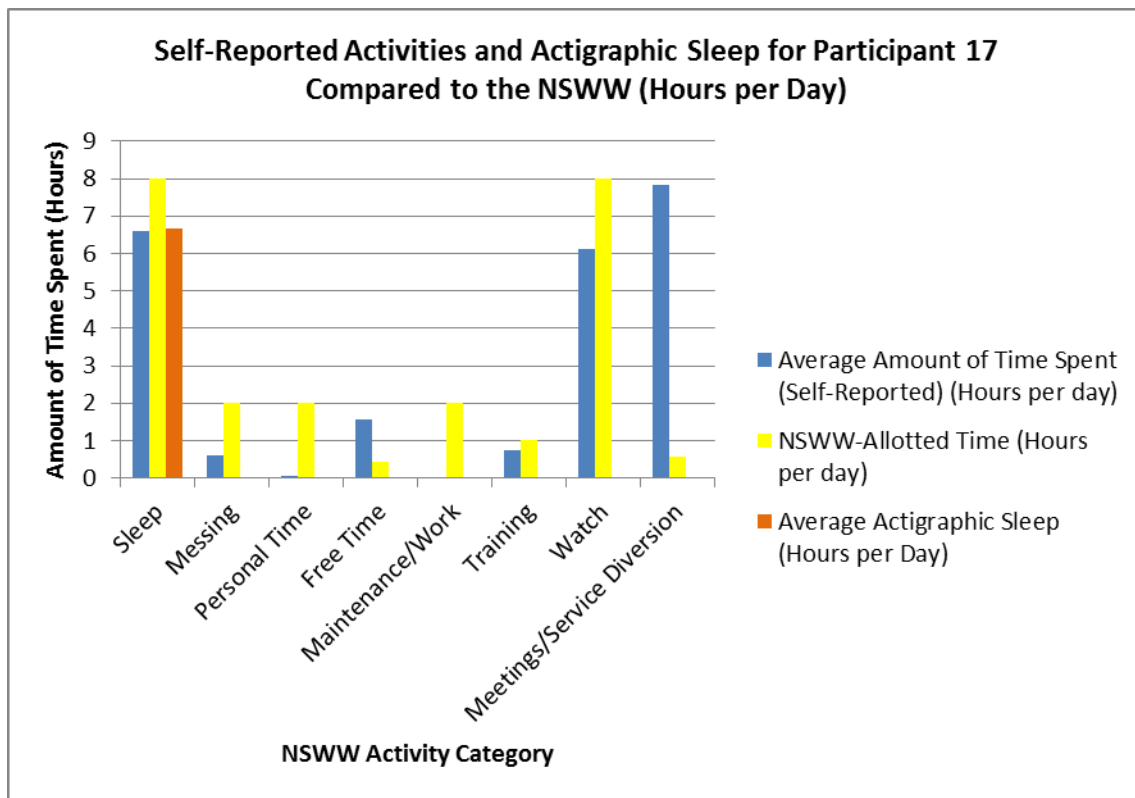
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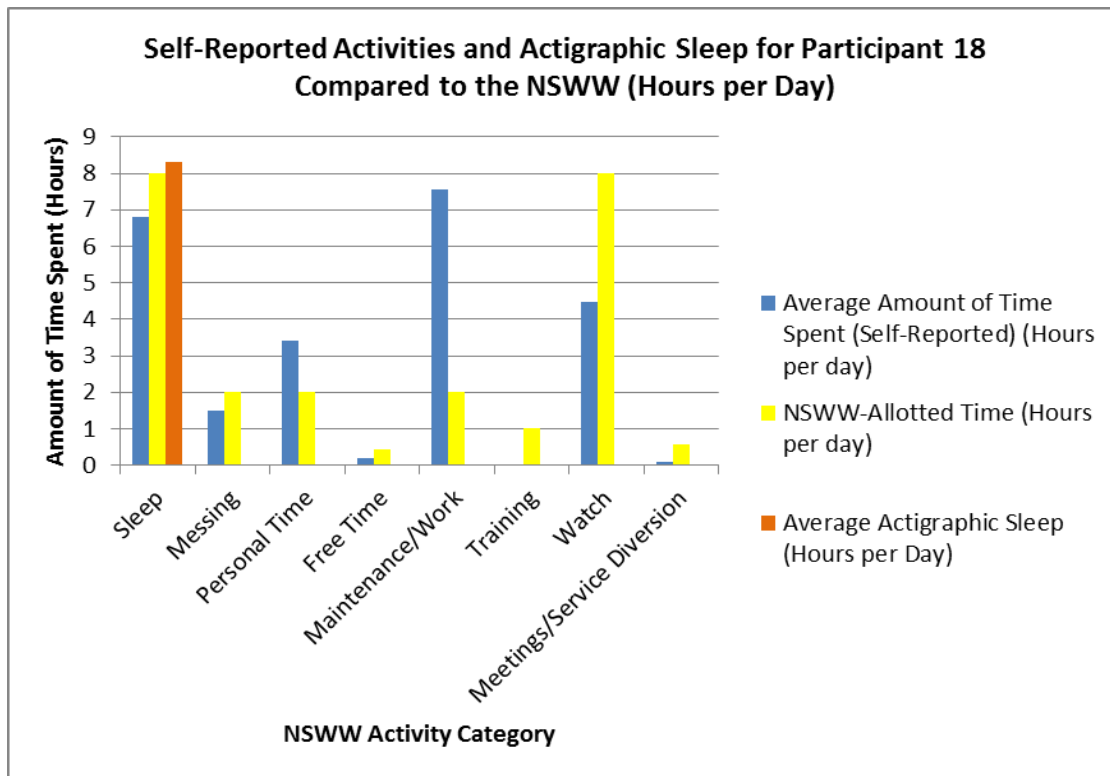
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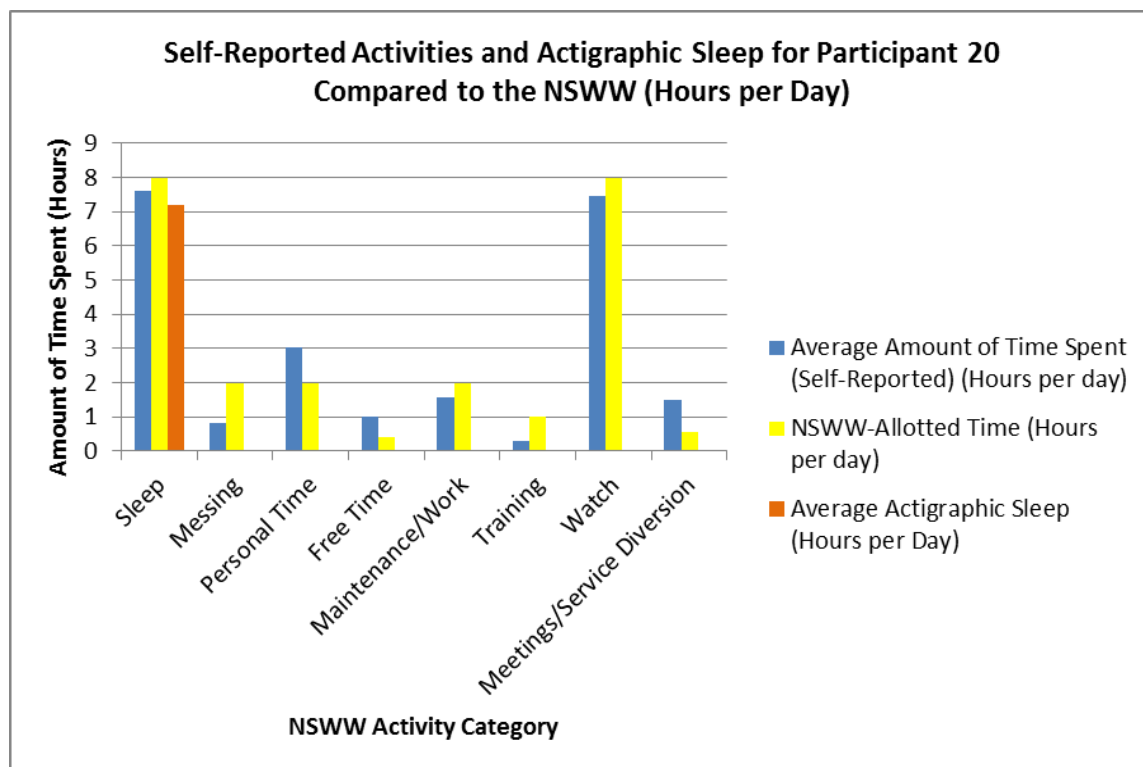
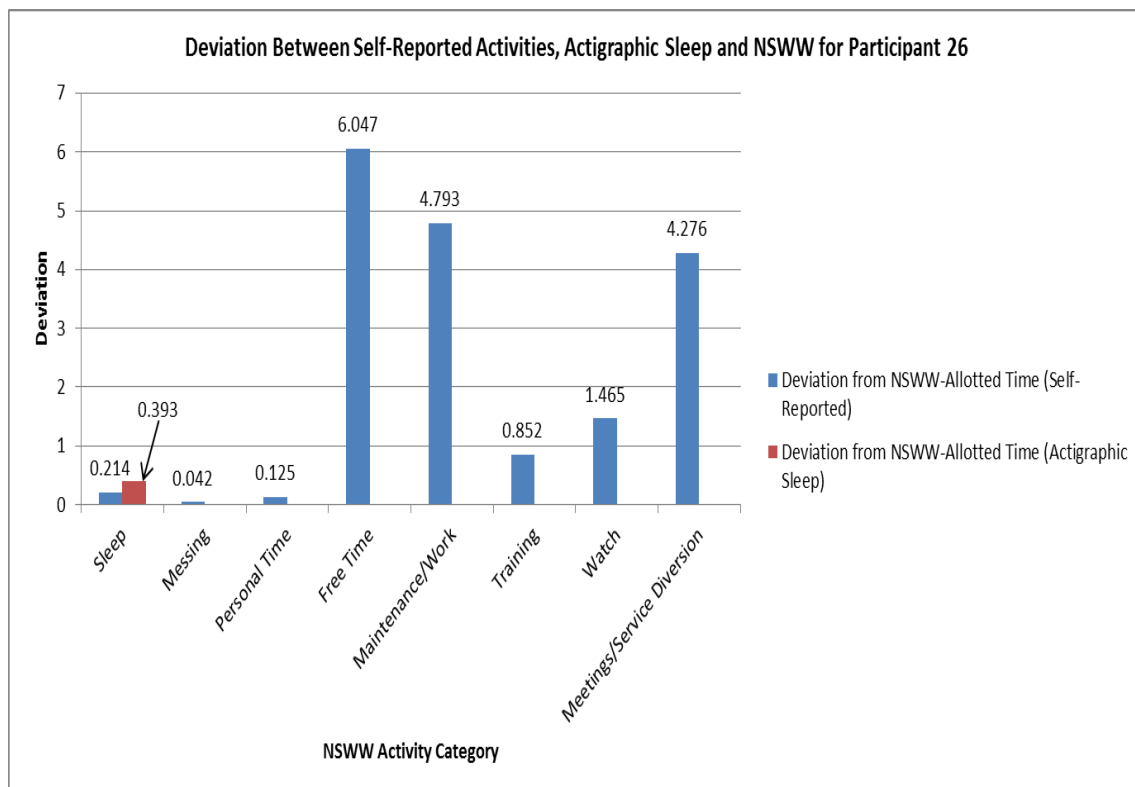Participant 18
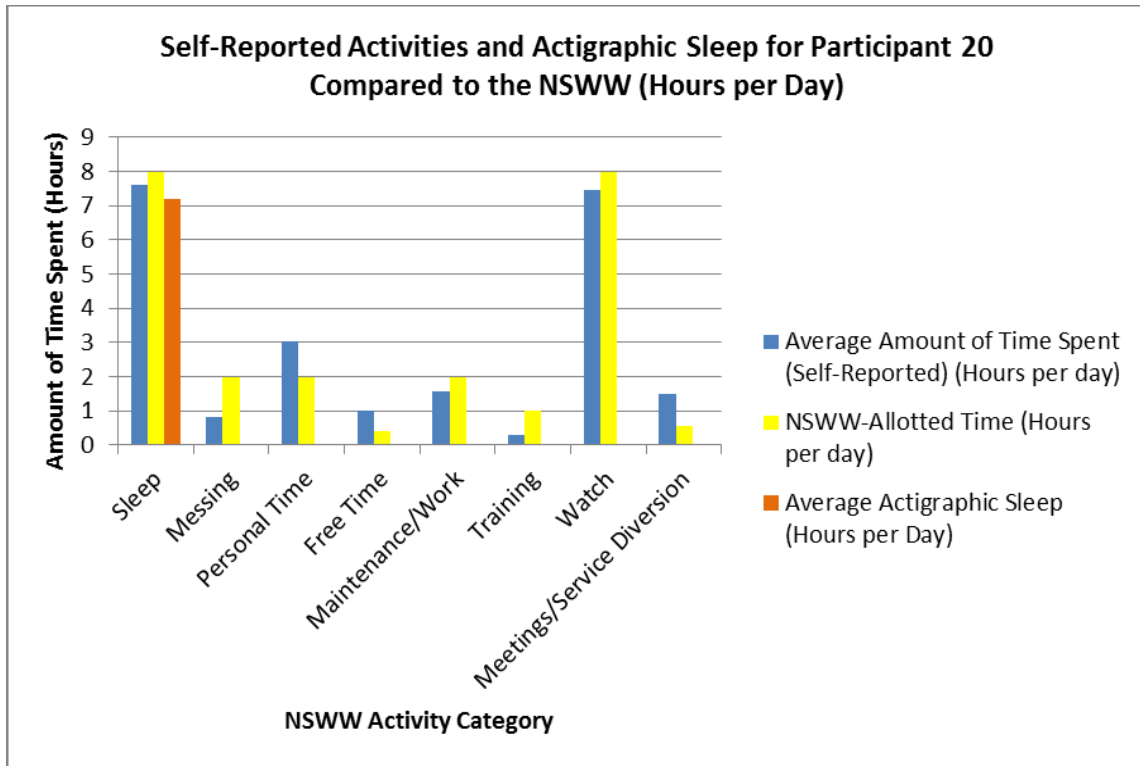
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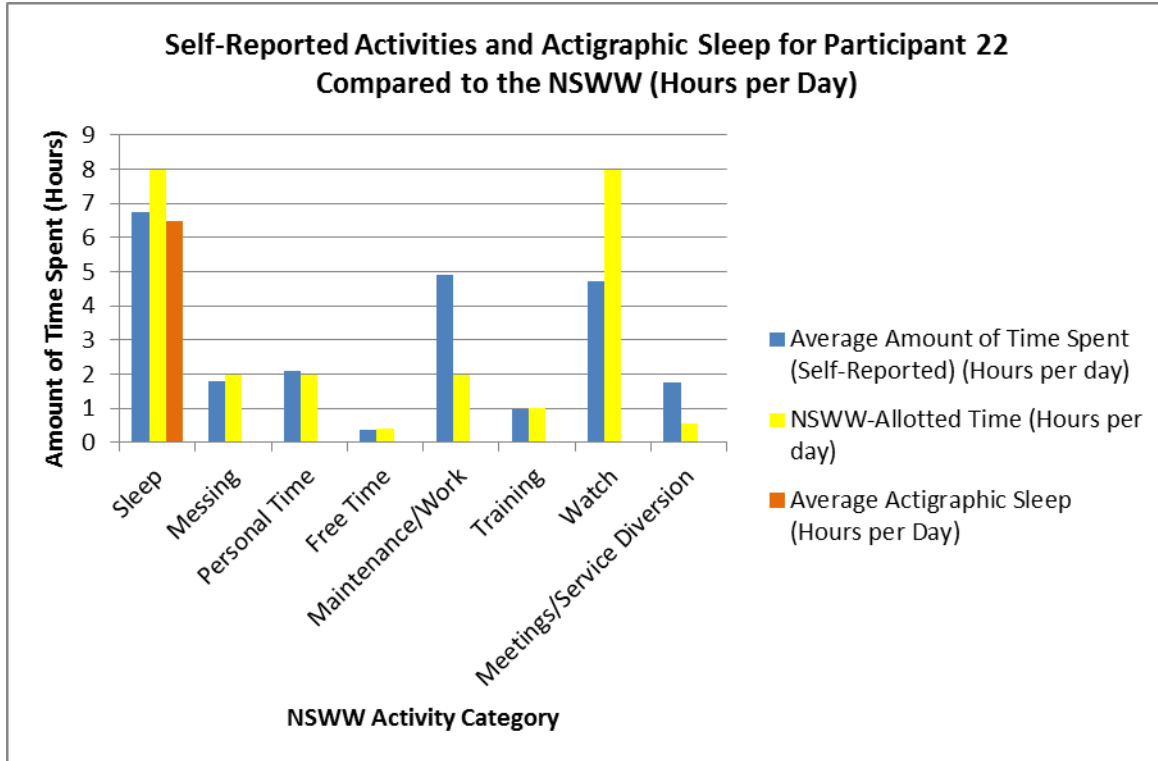
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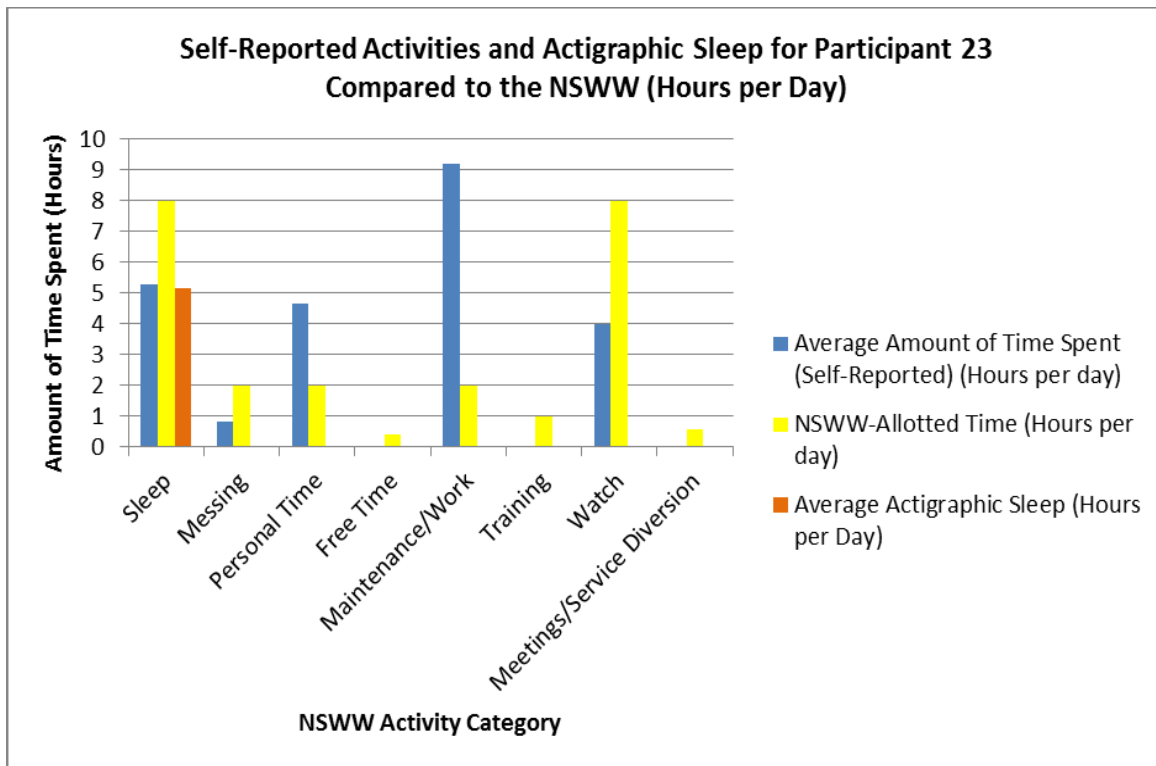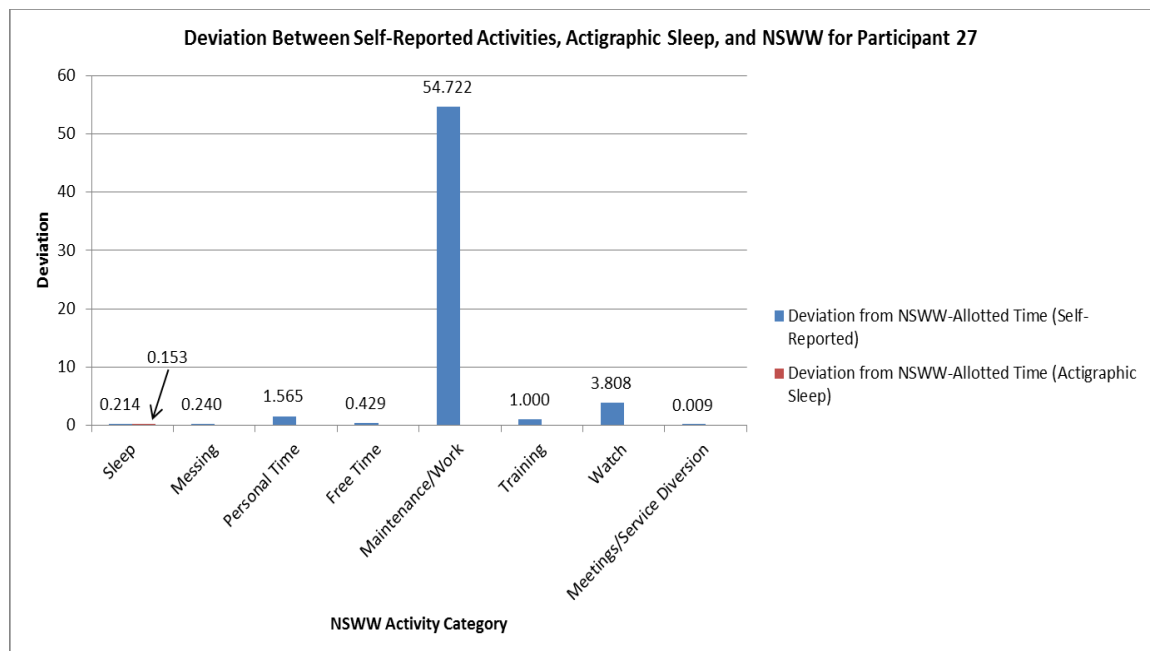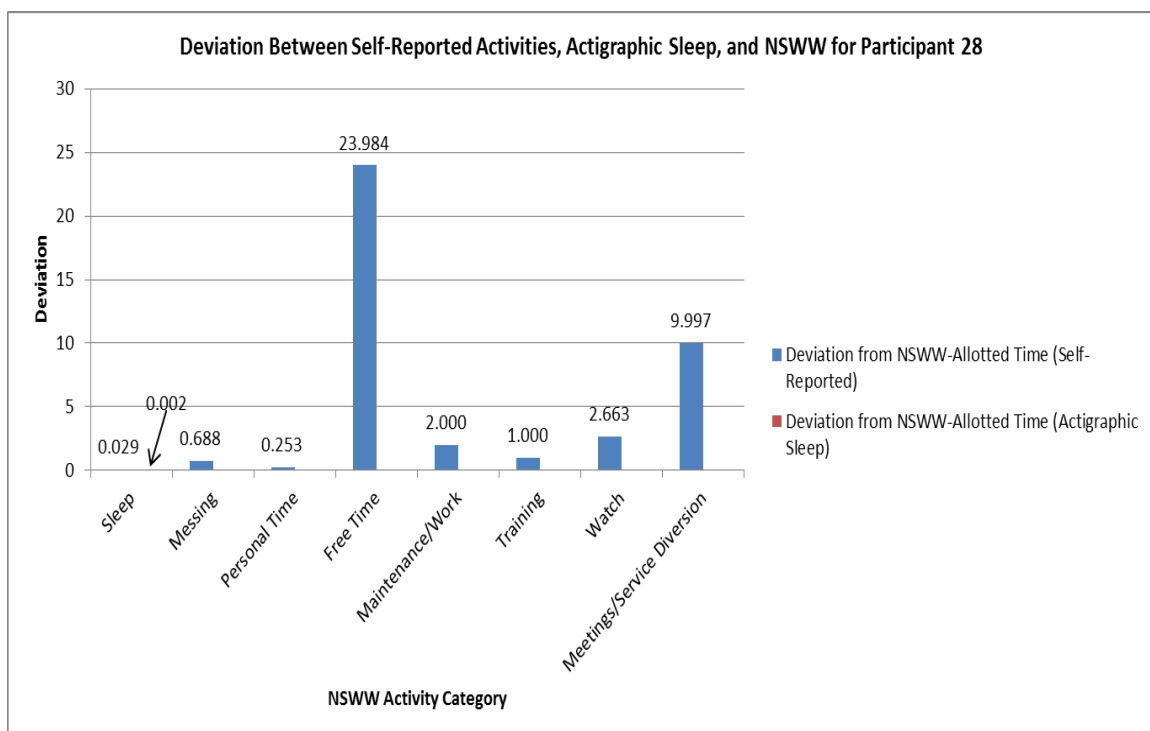

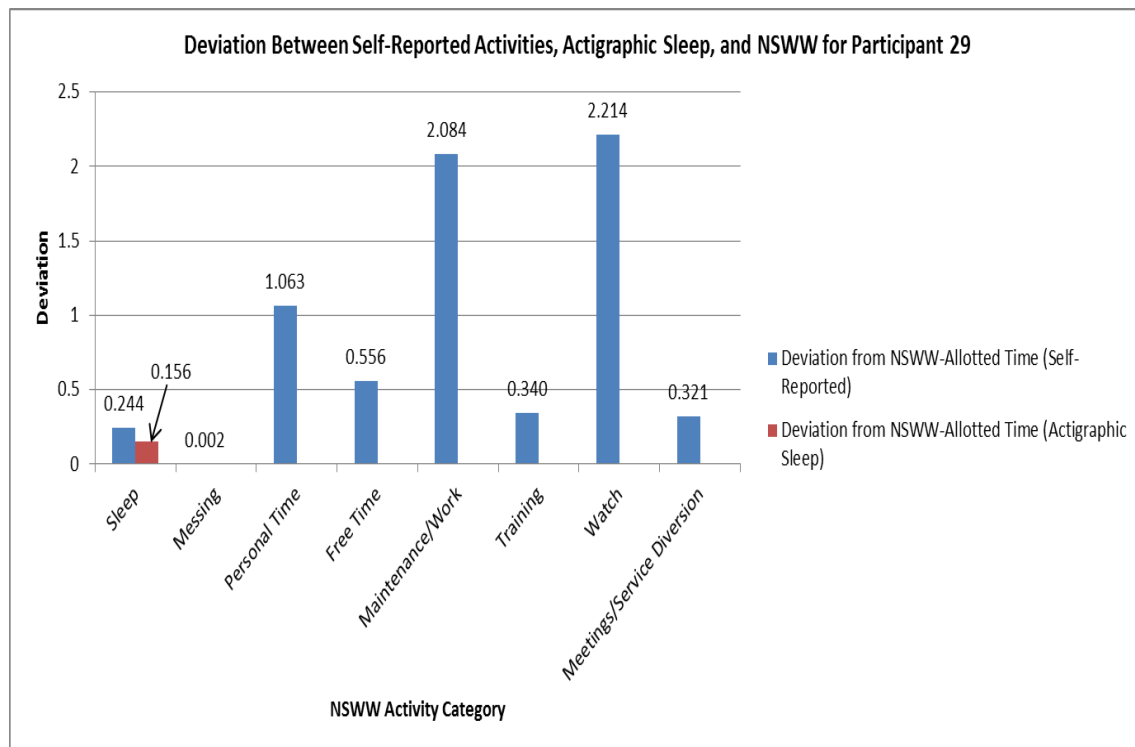
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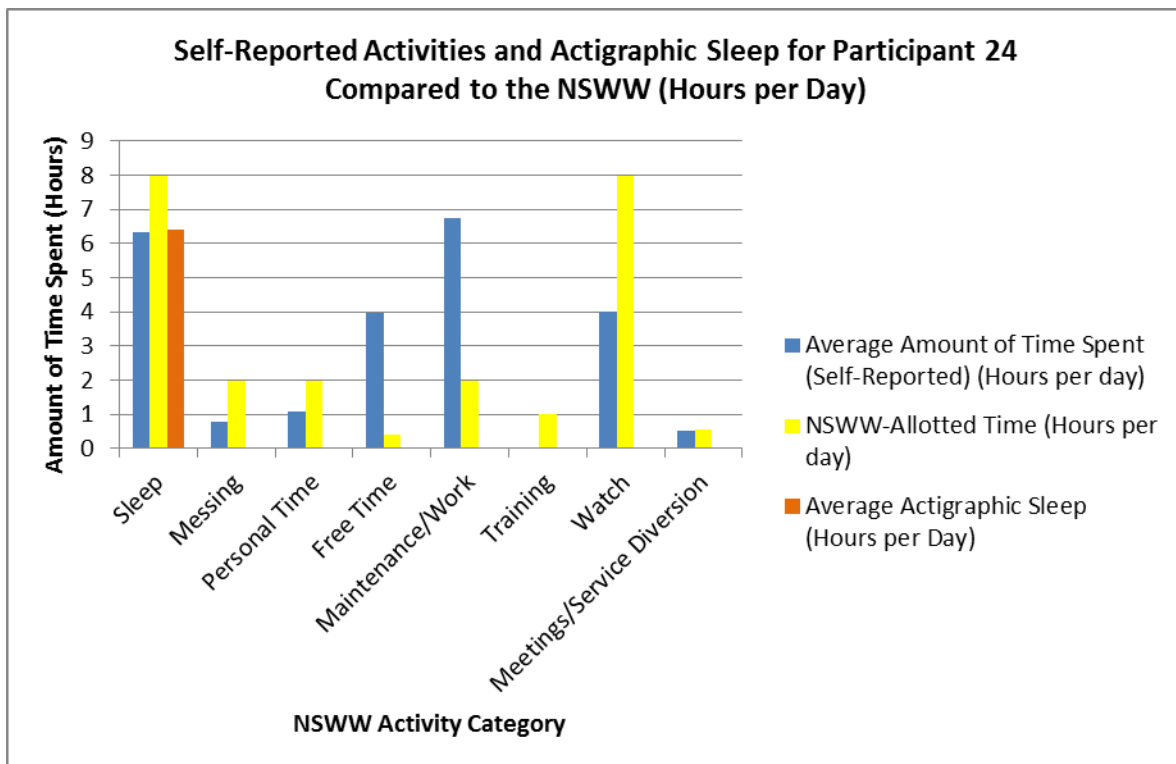
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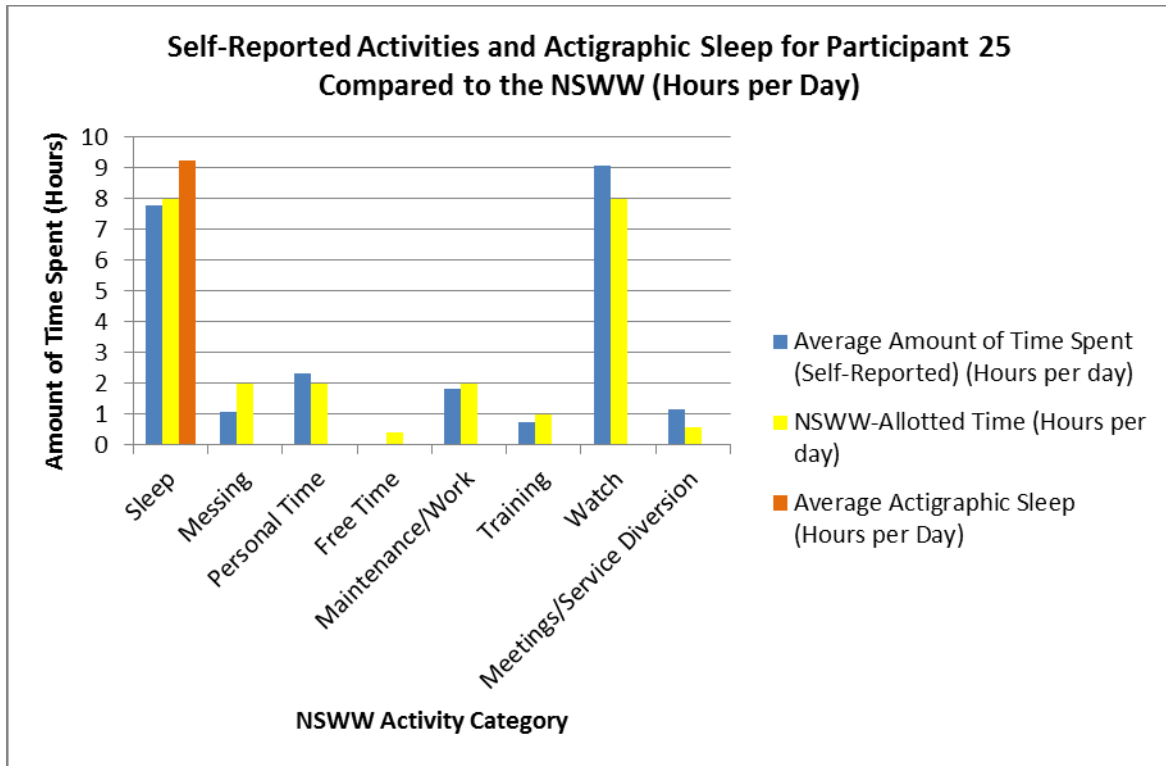
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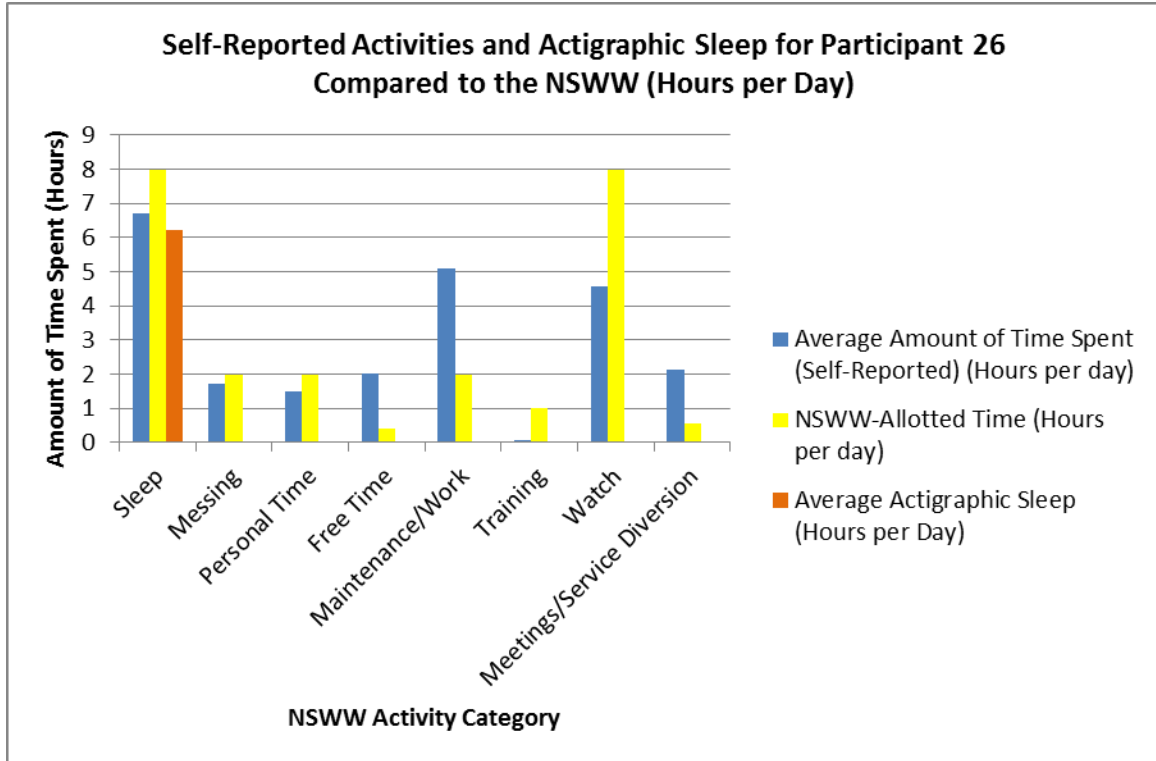
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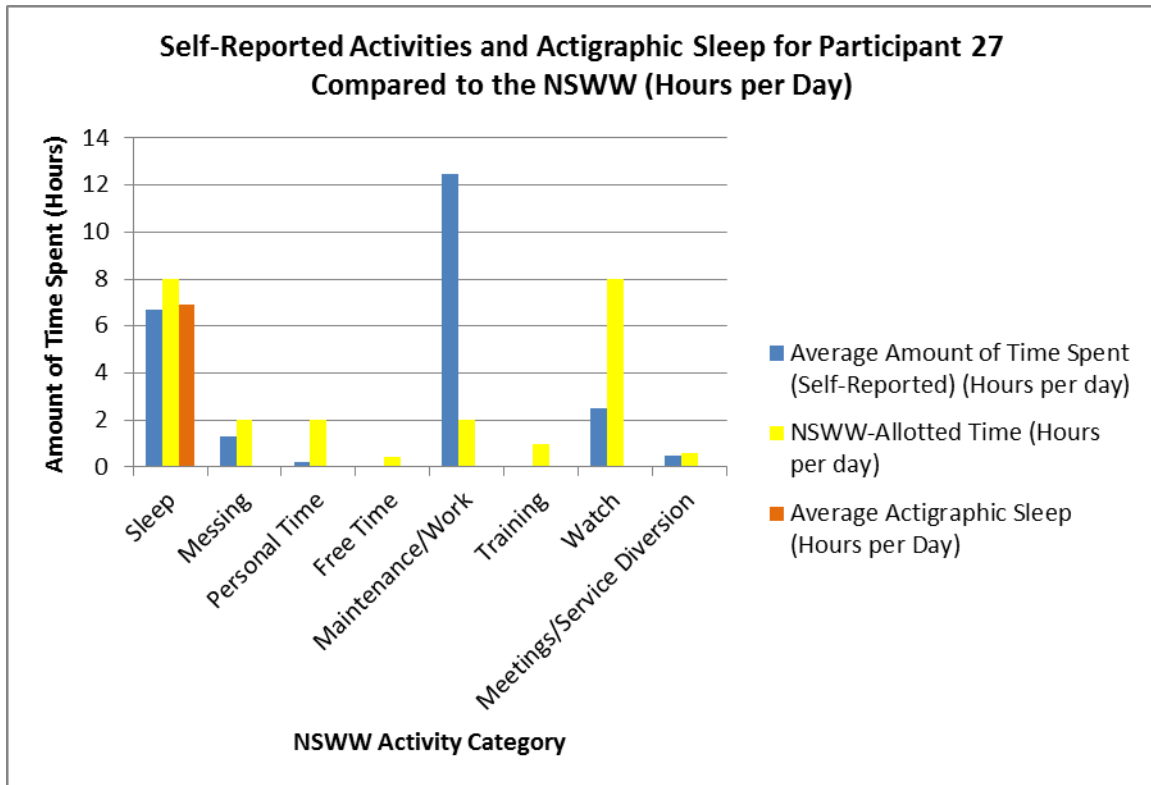
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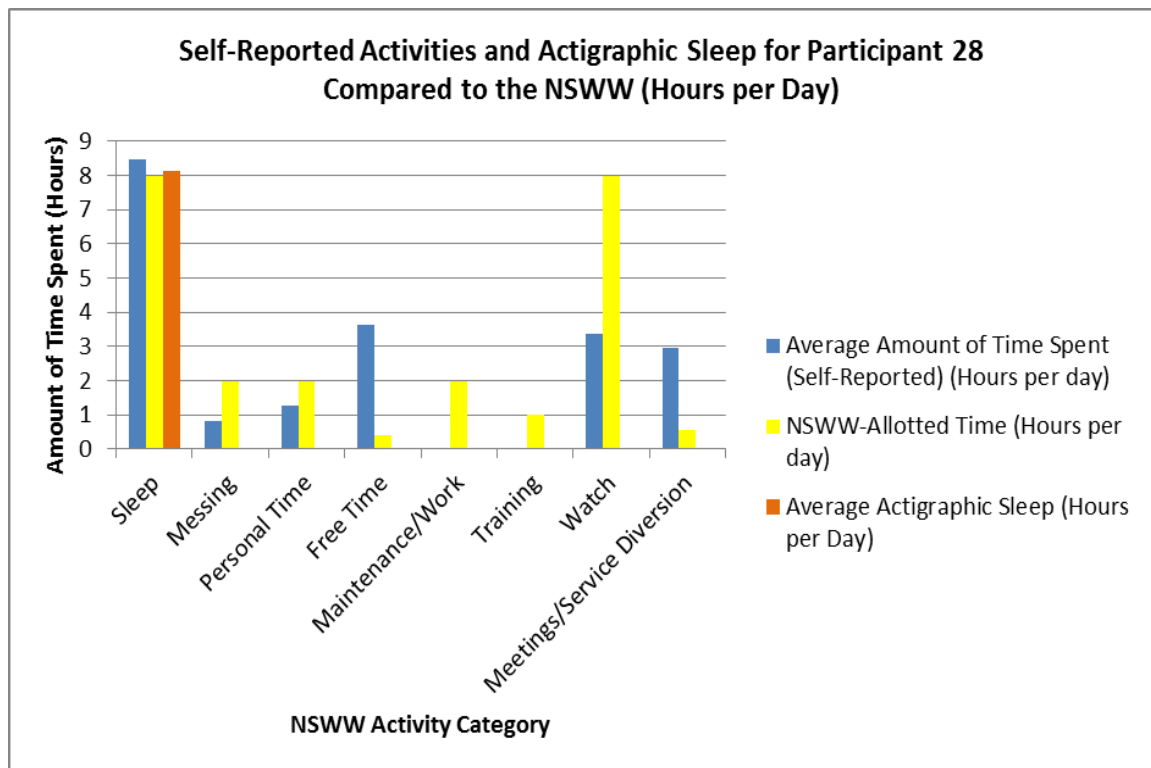
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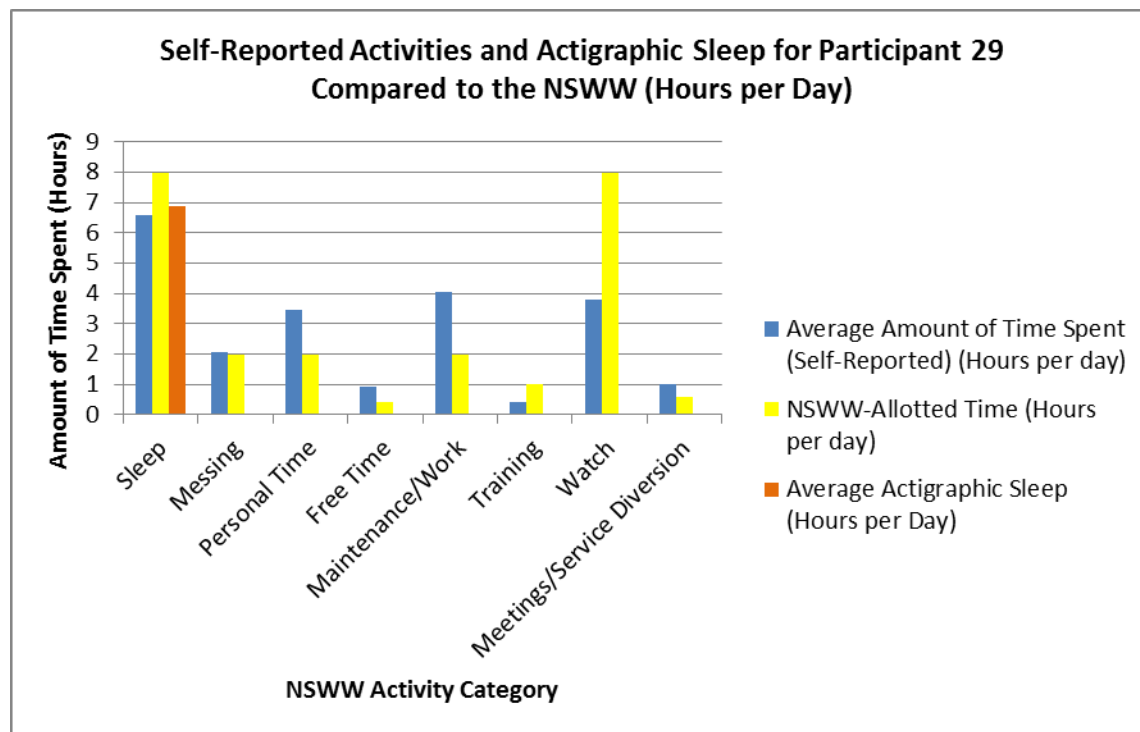
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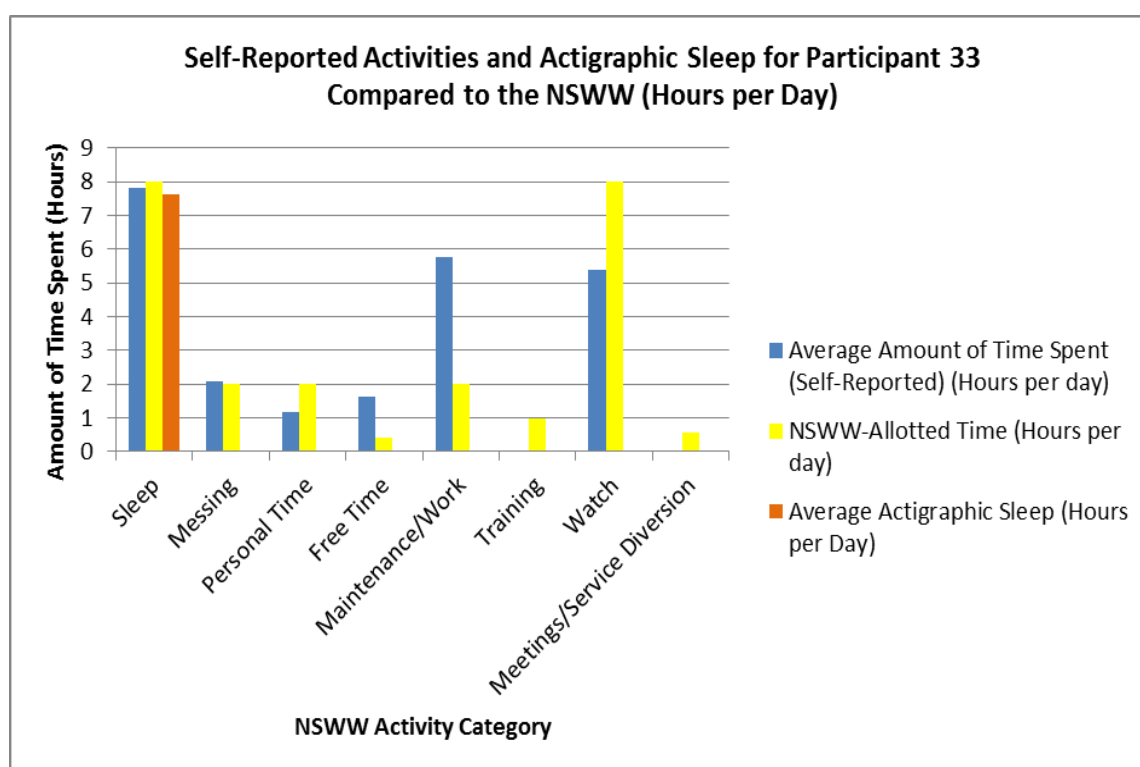
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Participant 33

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APPENDIX H.   INDIVIDUAL PARTICIPANT DIFFERENCE FROM THE NSWW
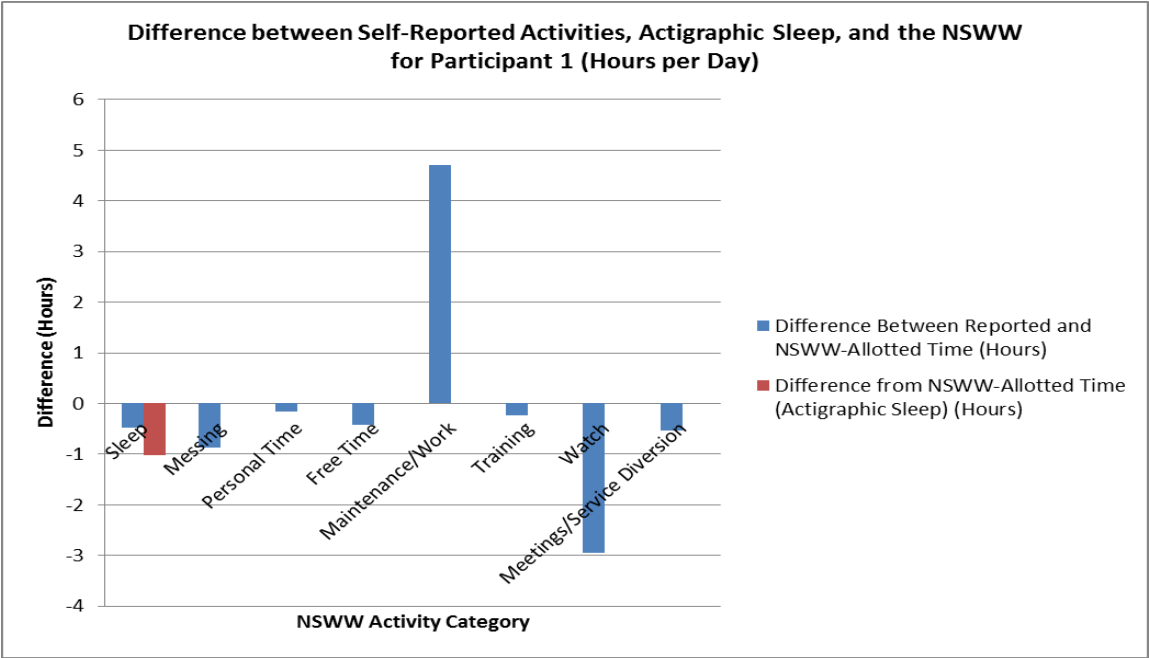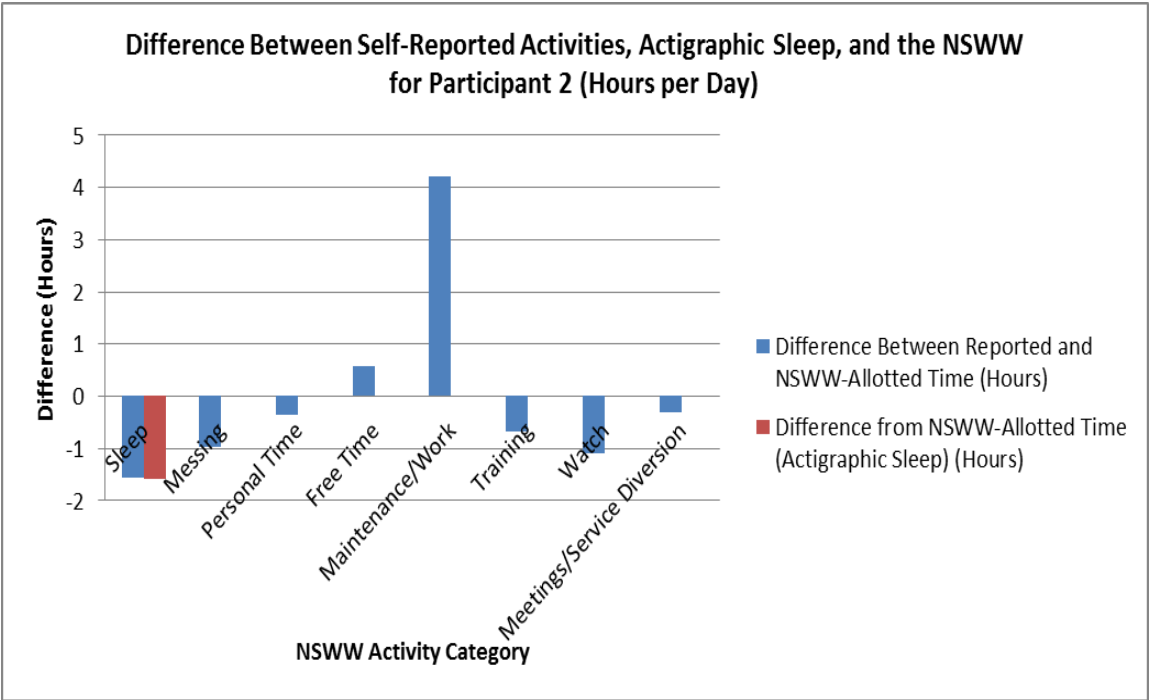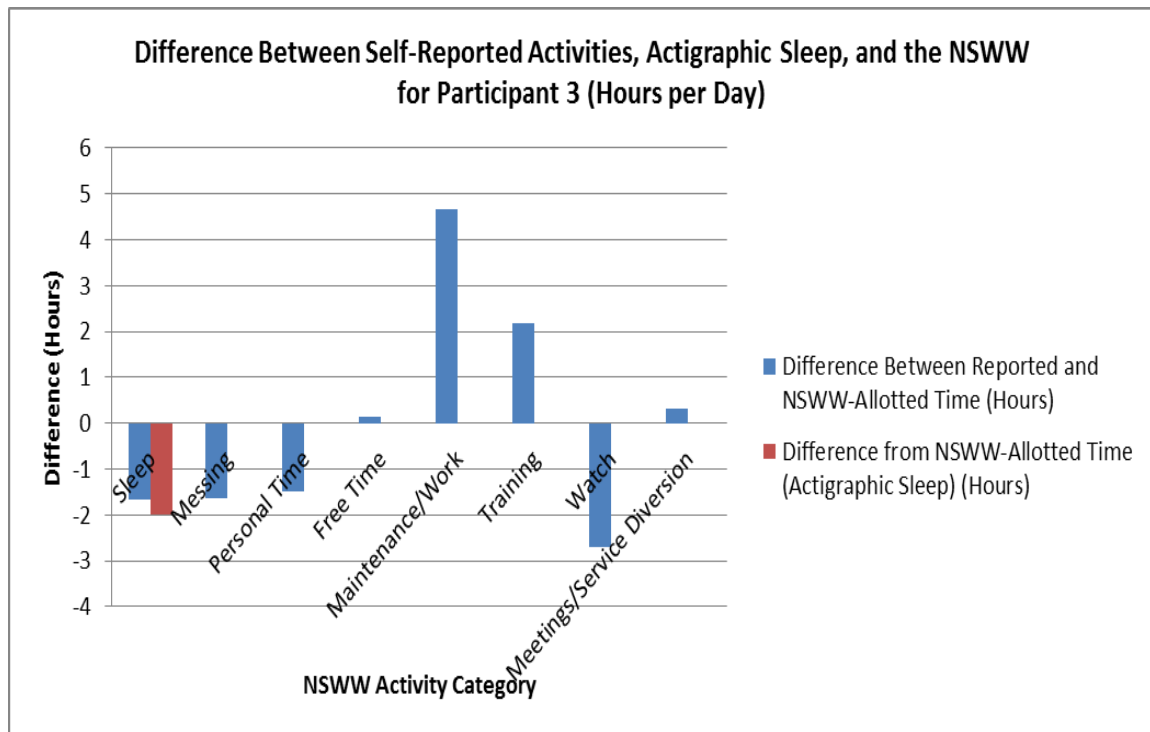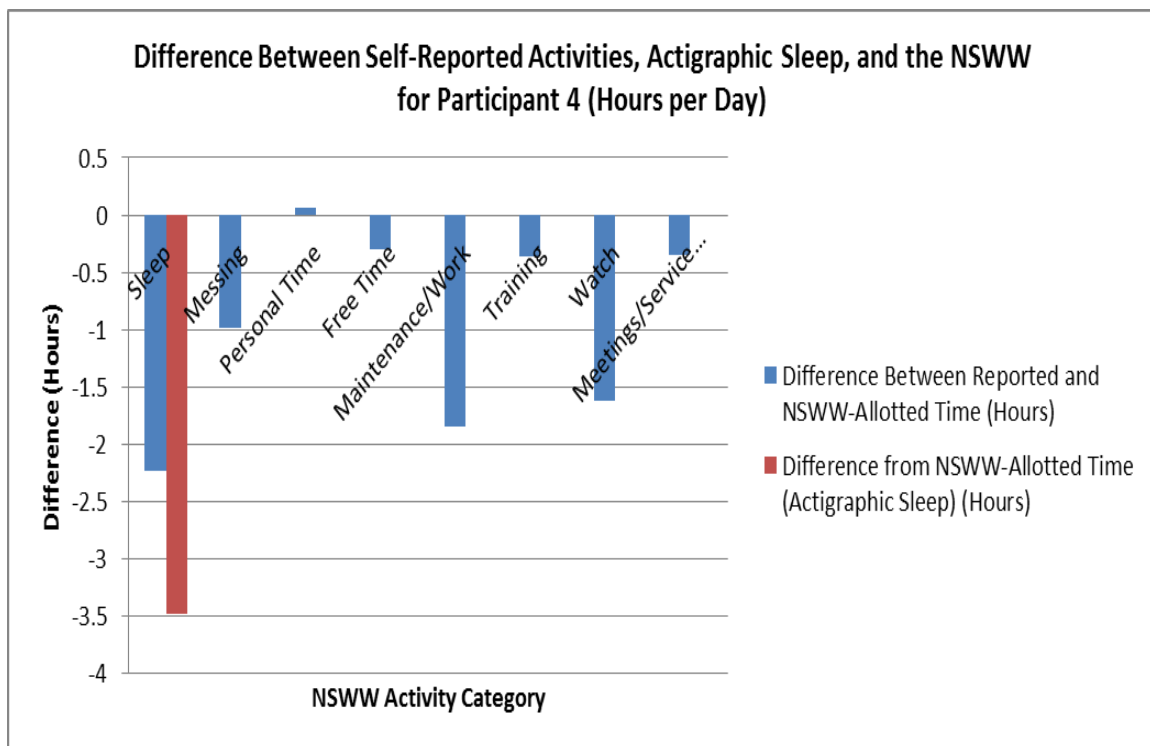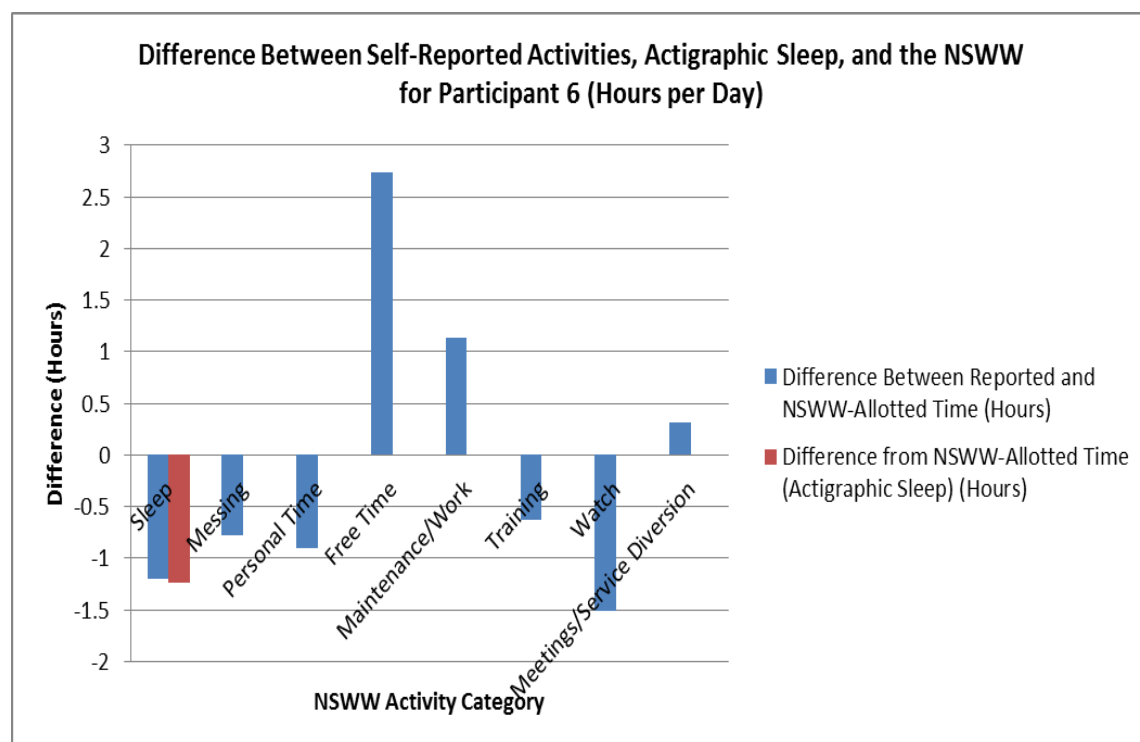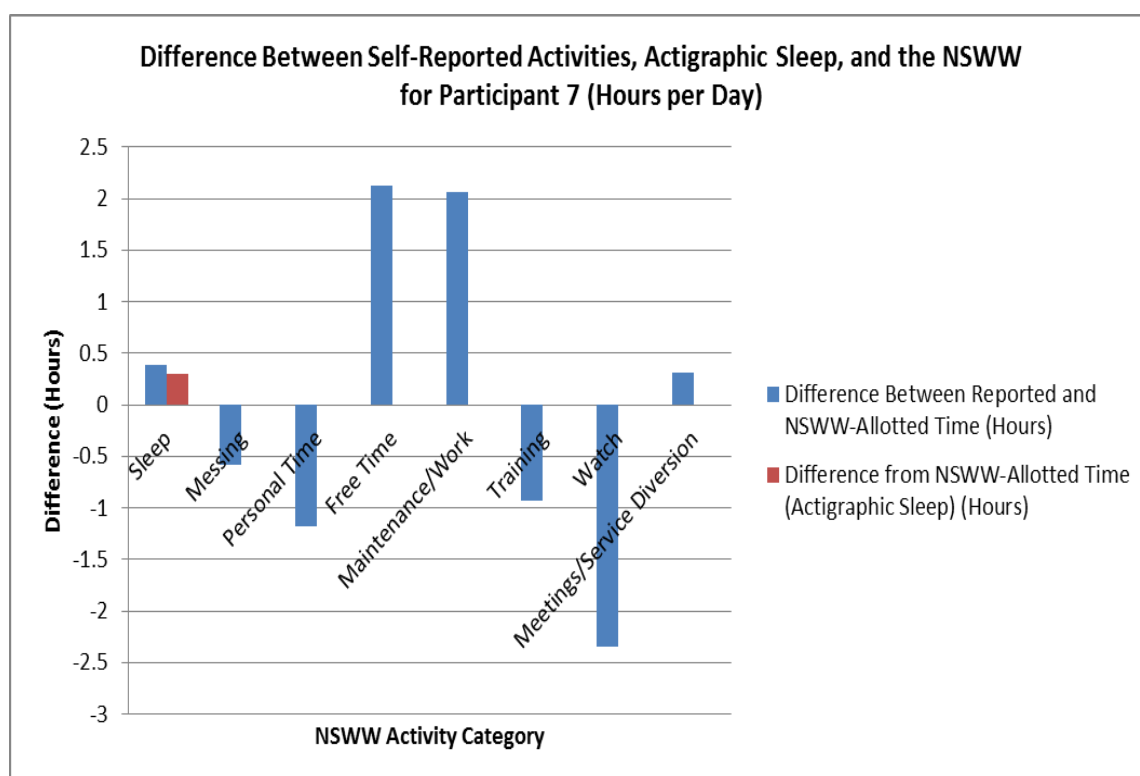
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Participant 3

Participant 4

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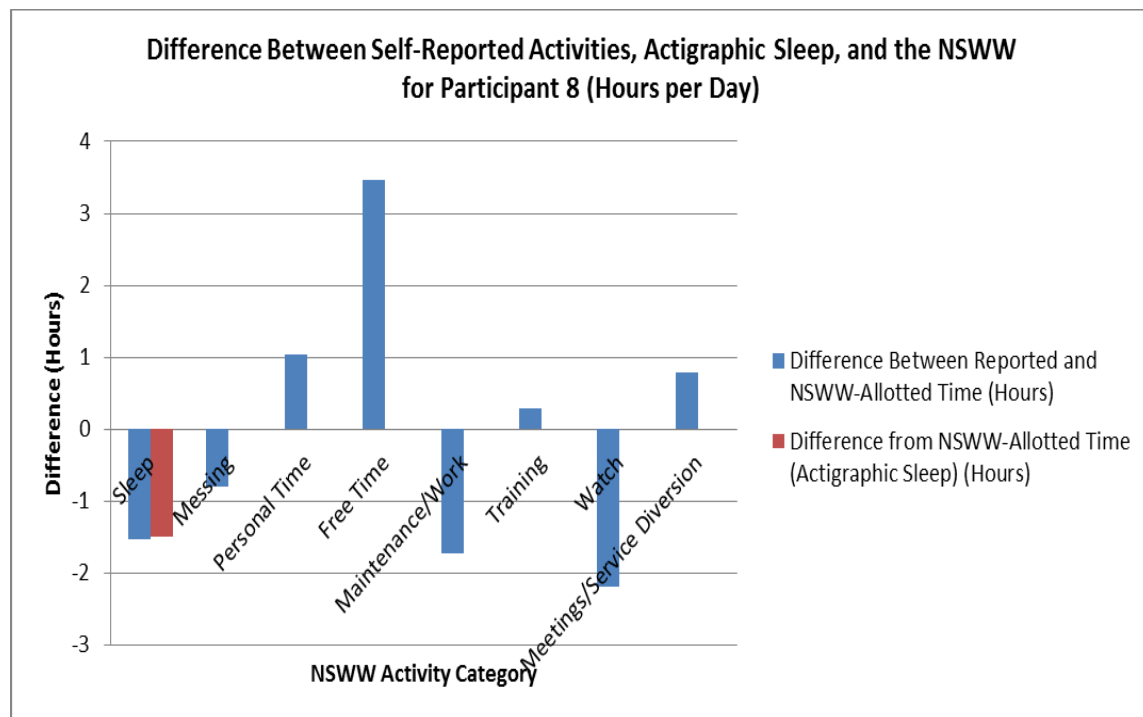
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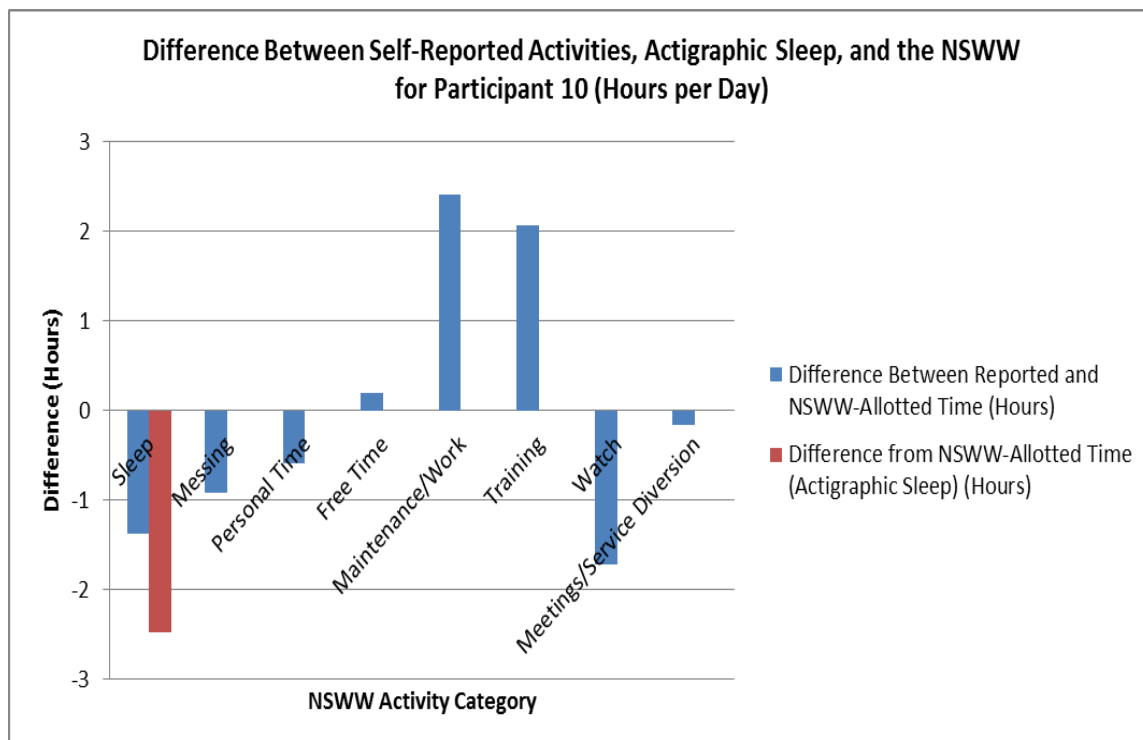
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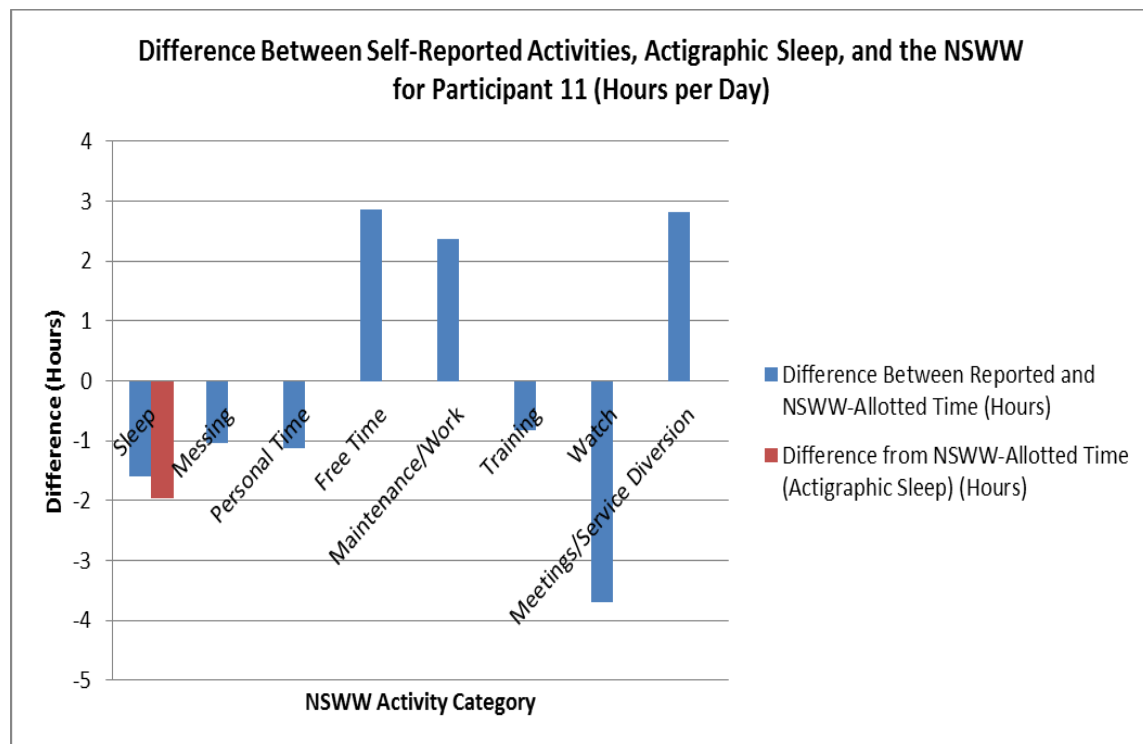
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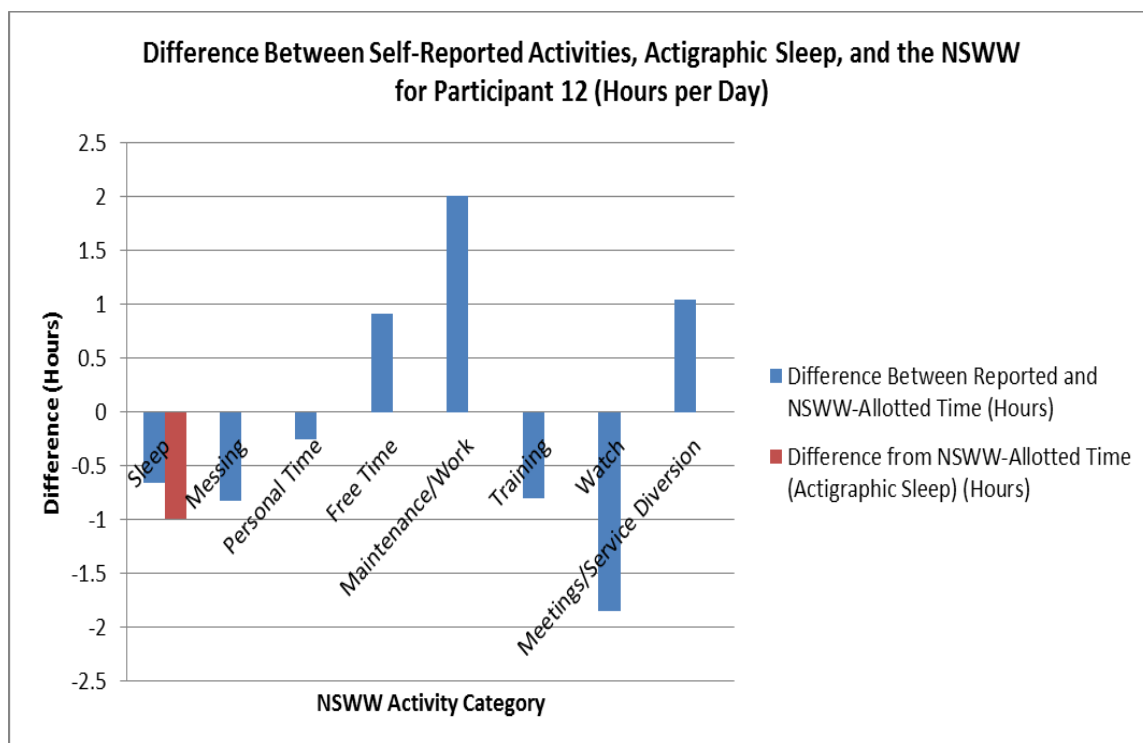
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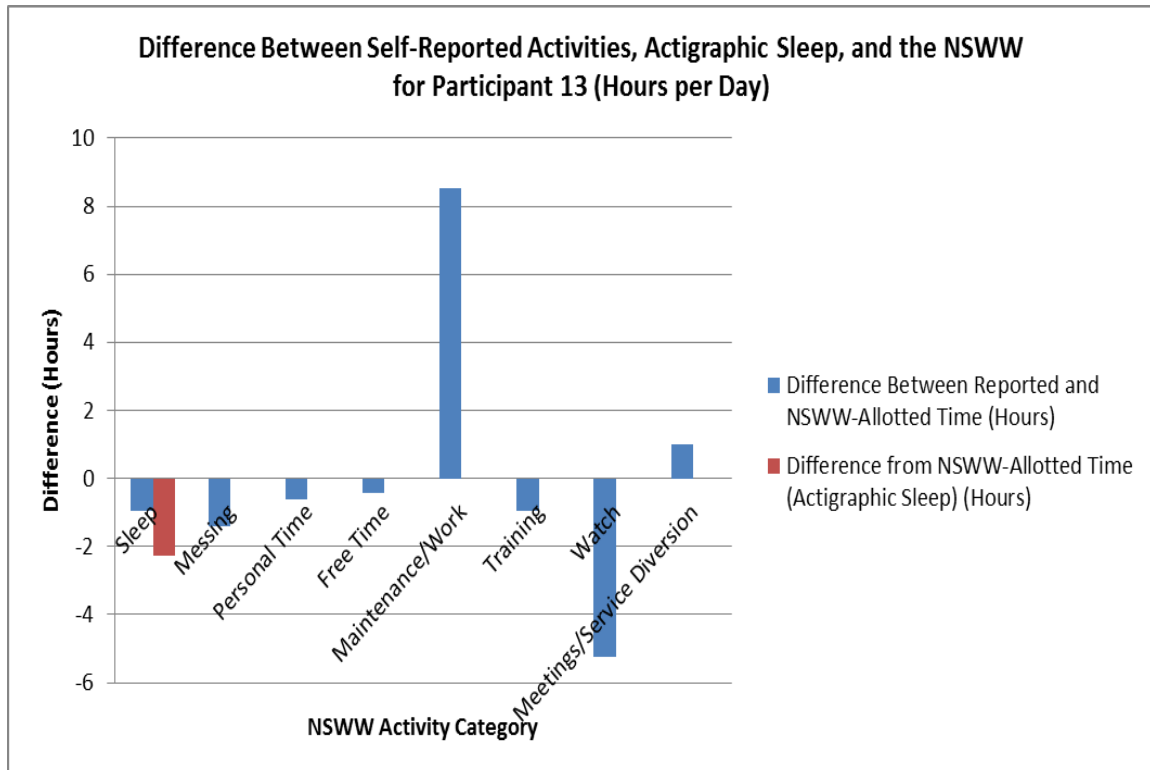
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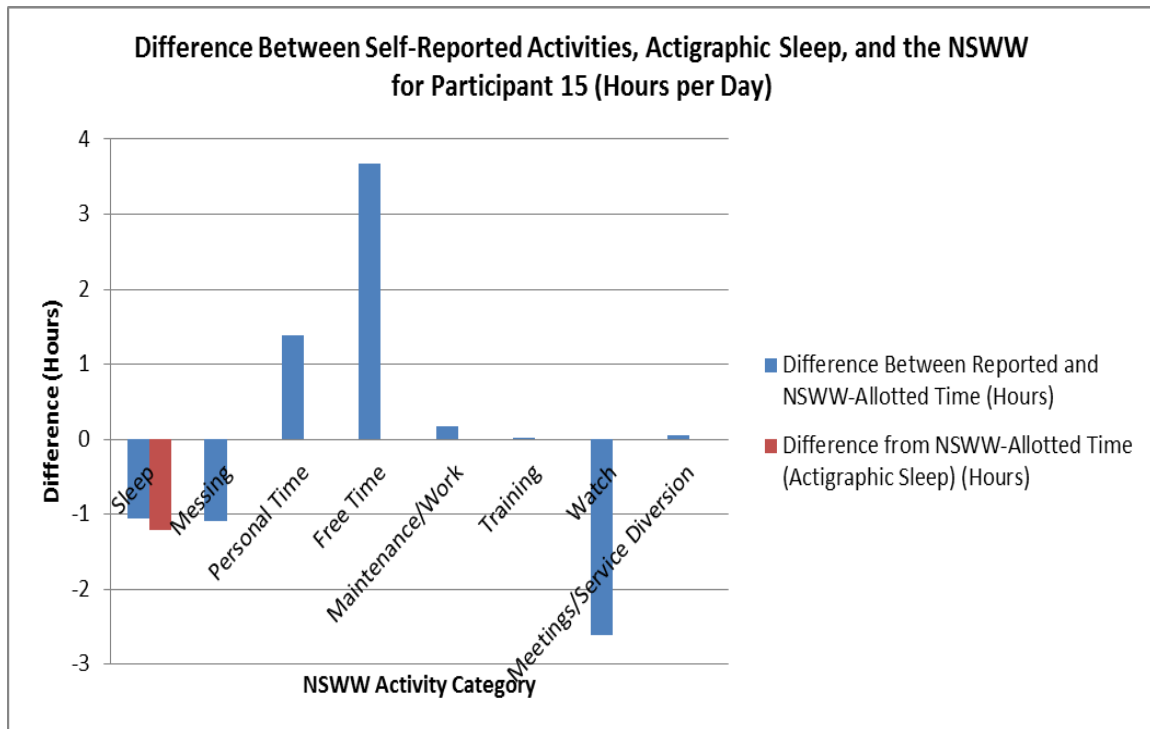
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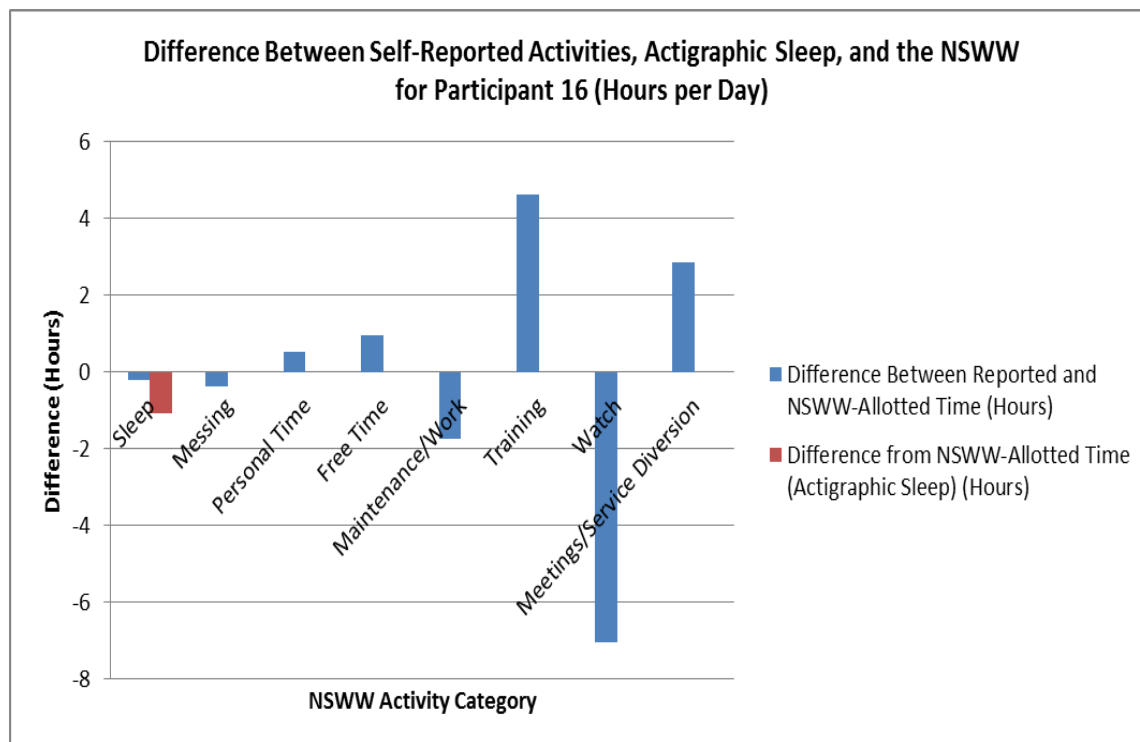
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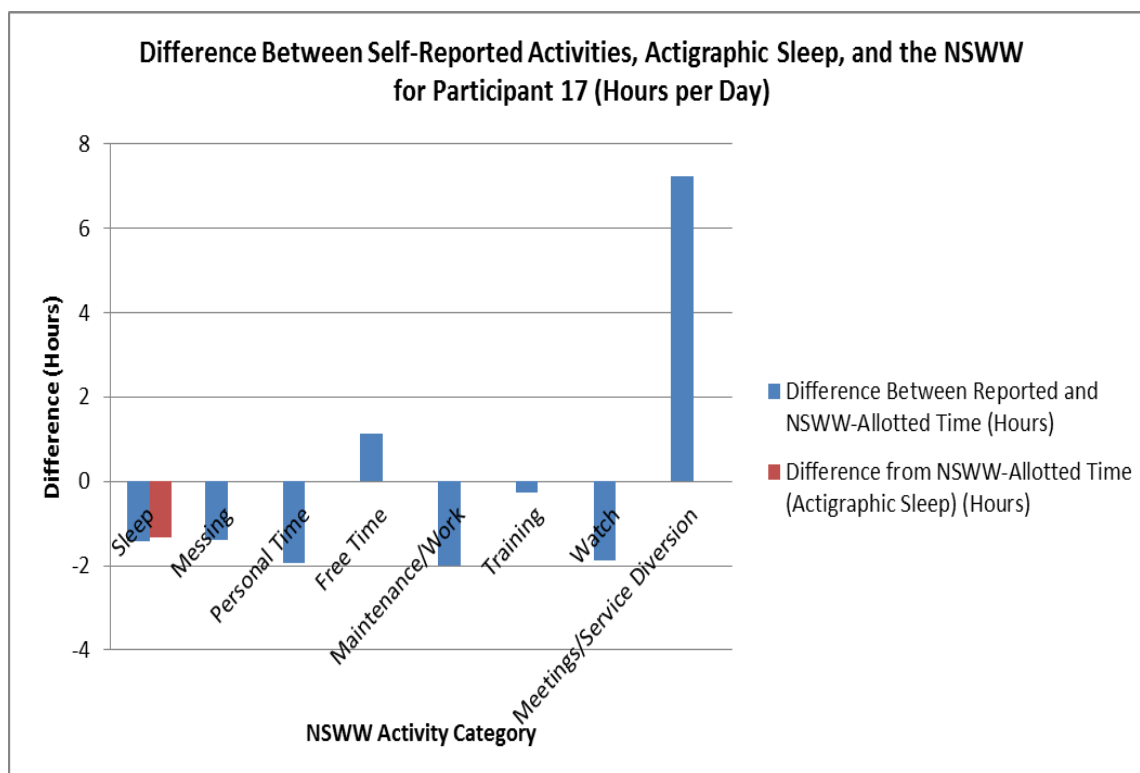
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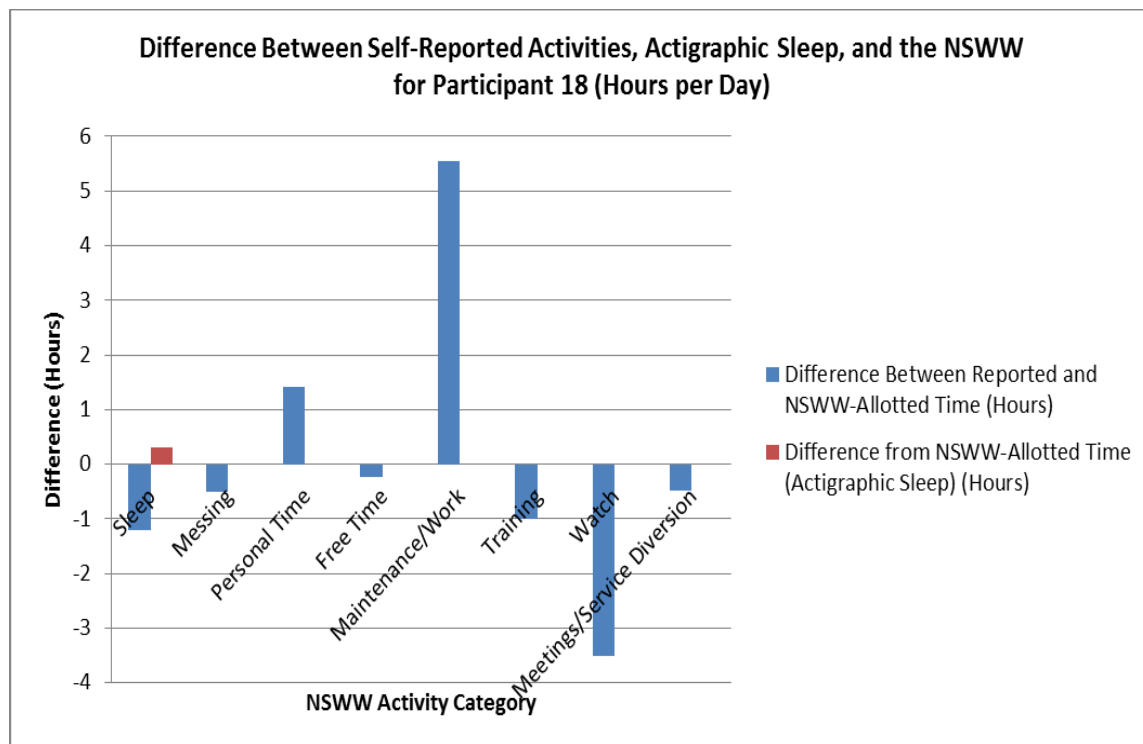
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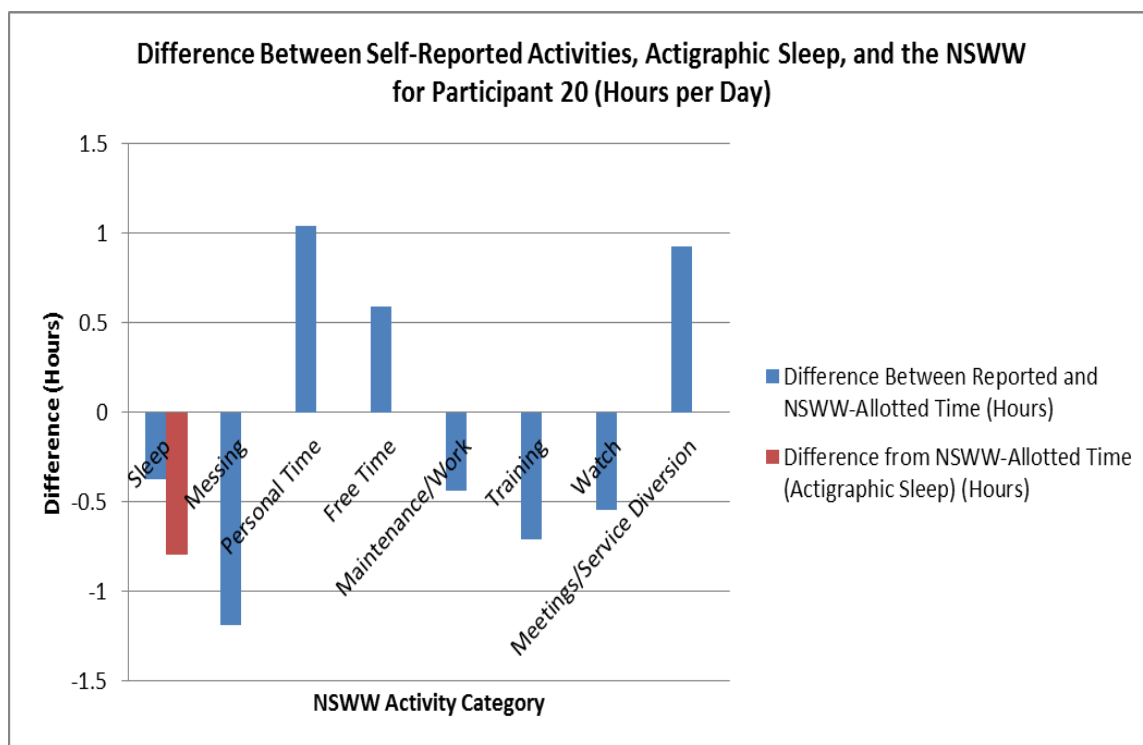
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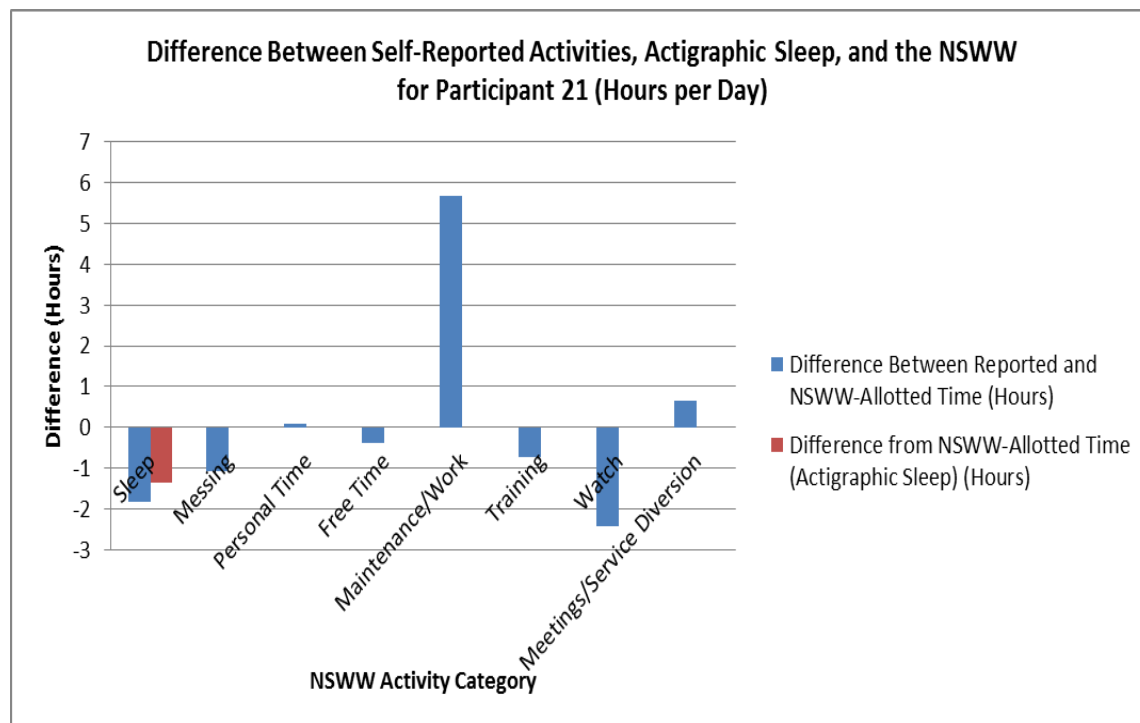
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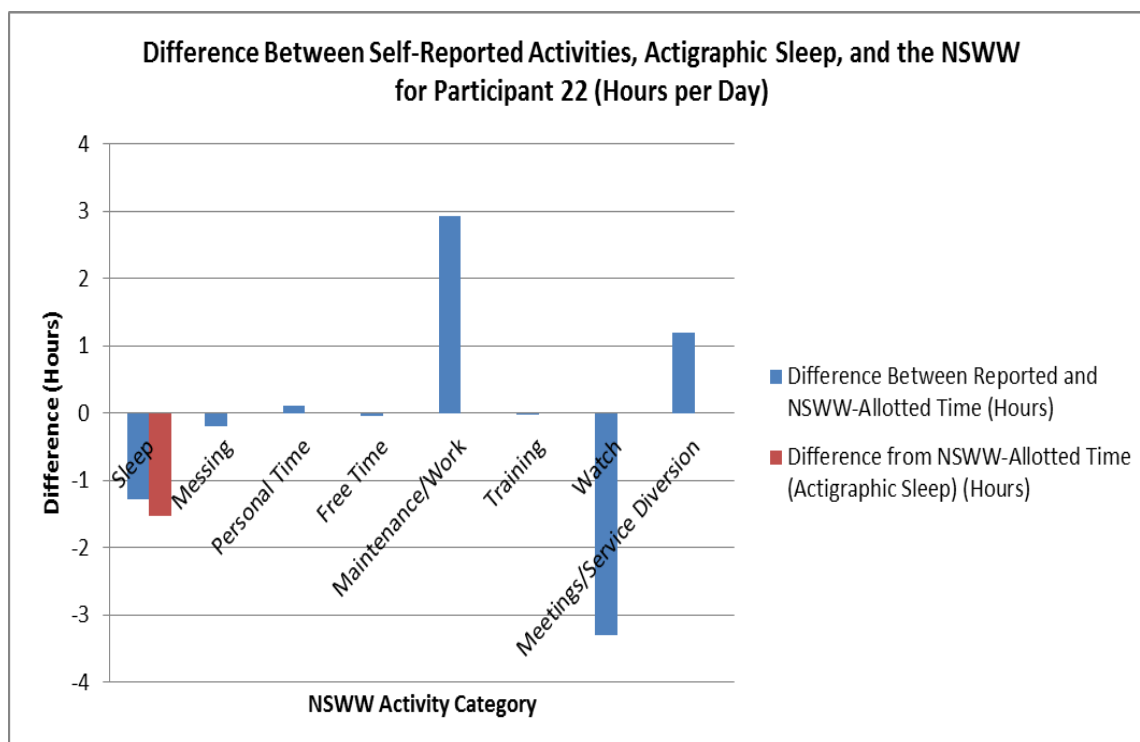
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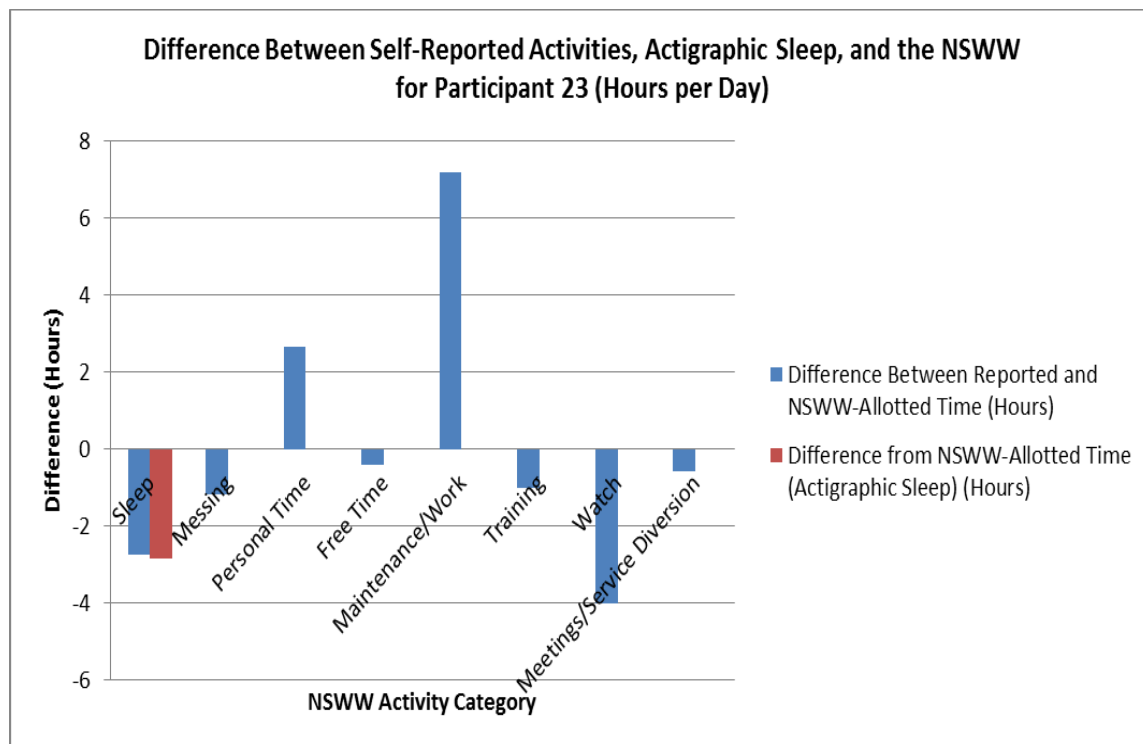
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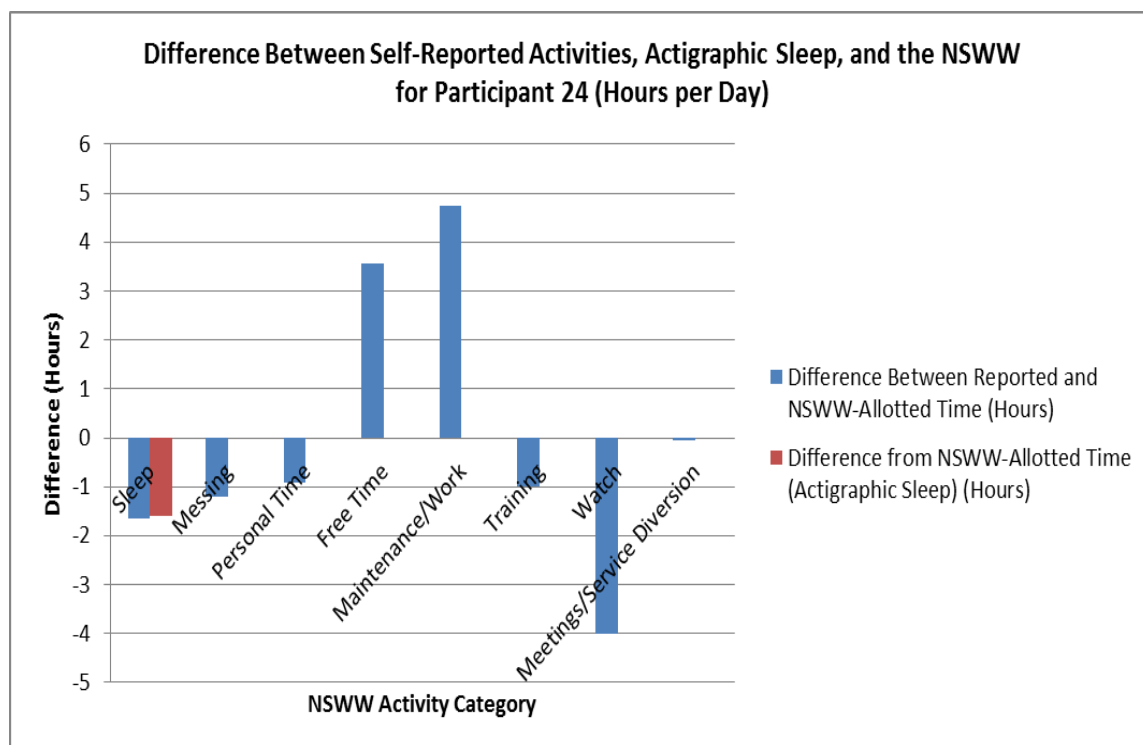
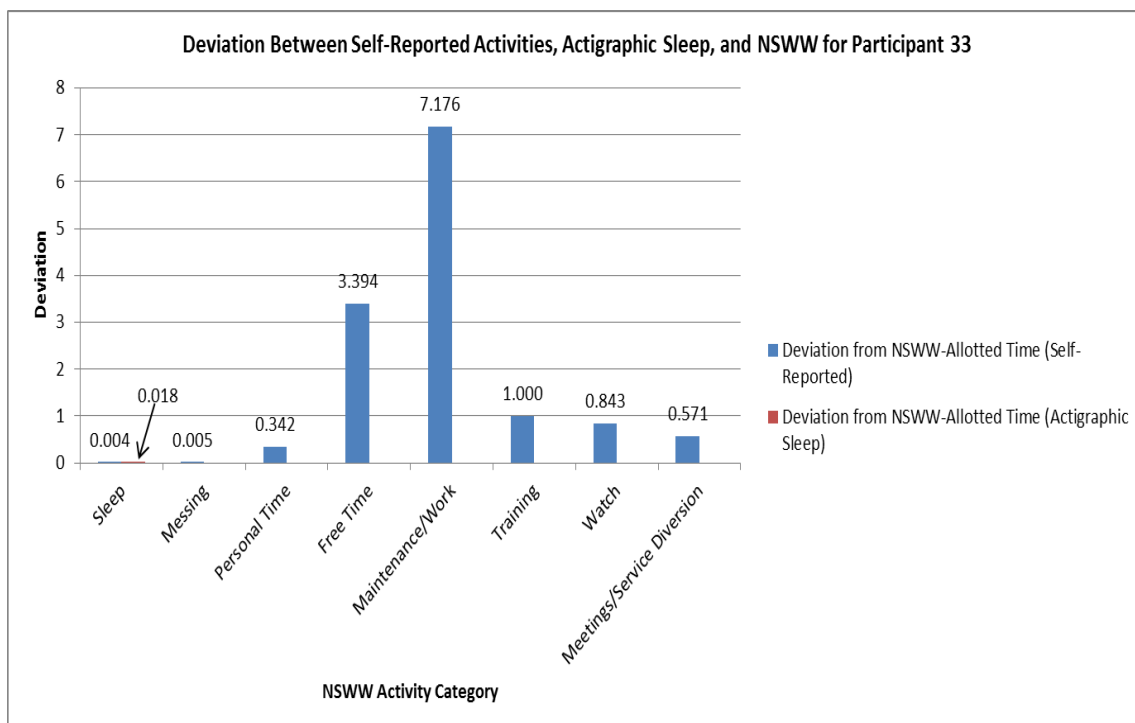Participant 23
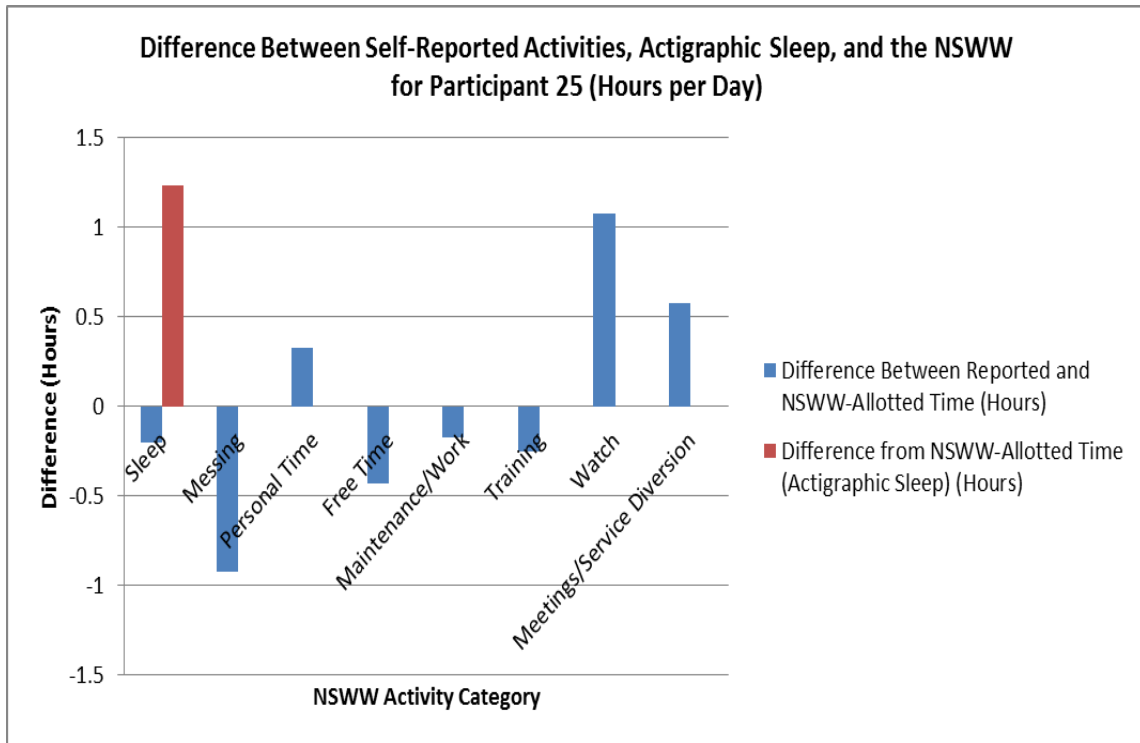
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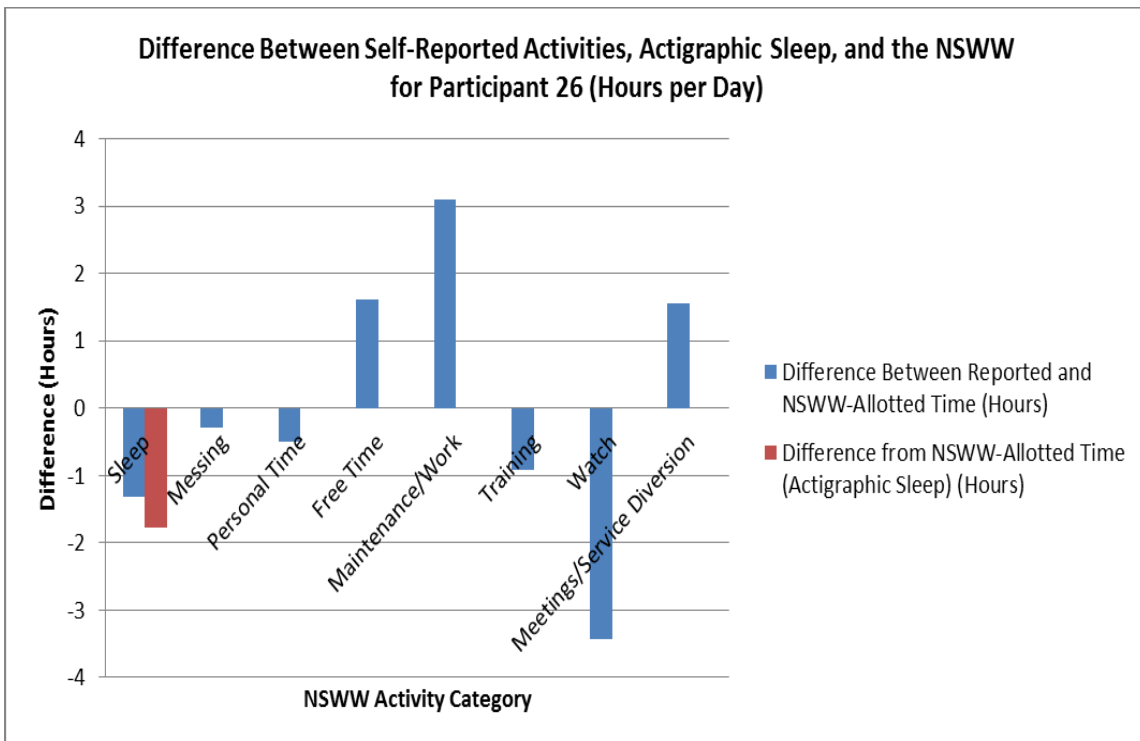
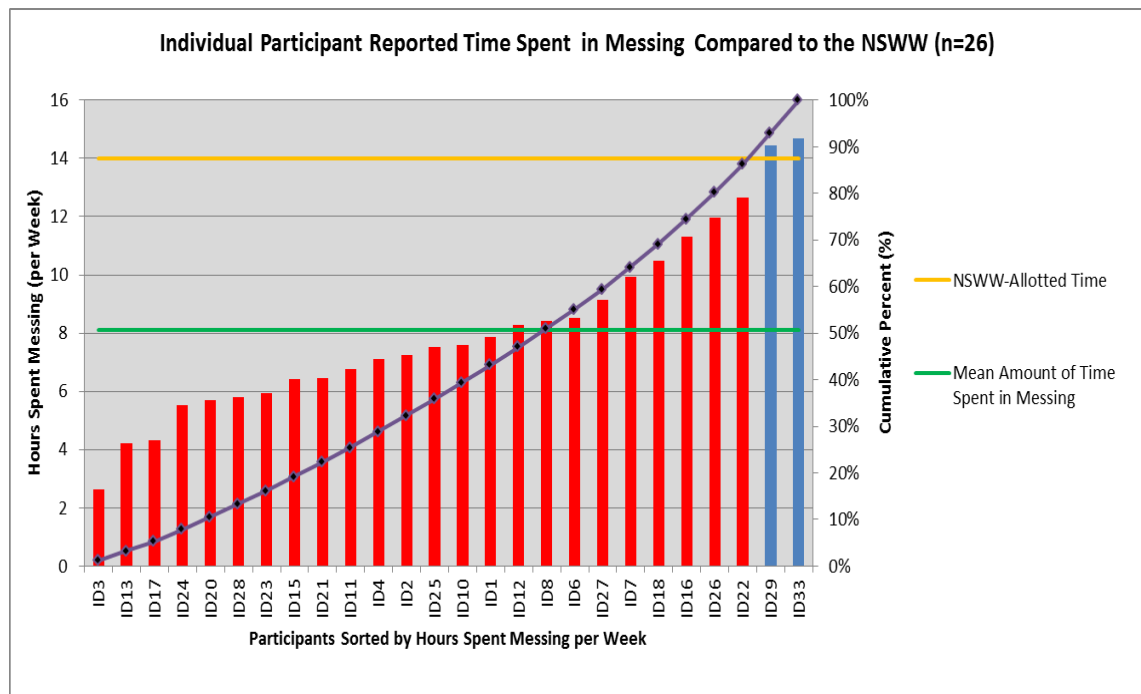Participant 25
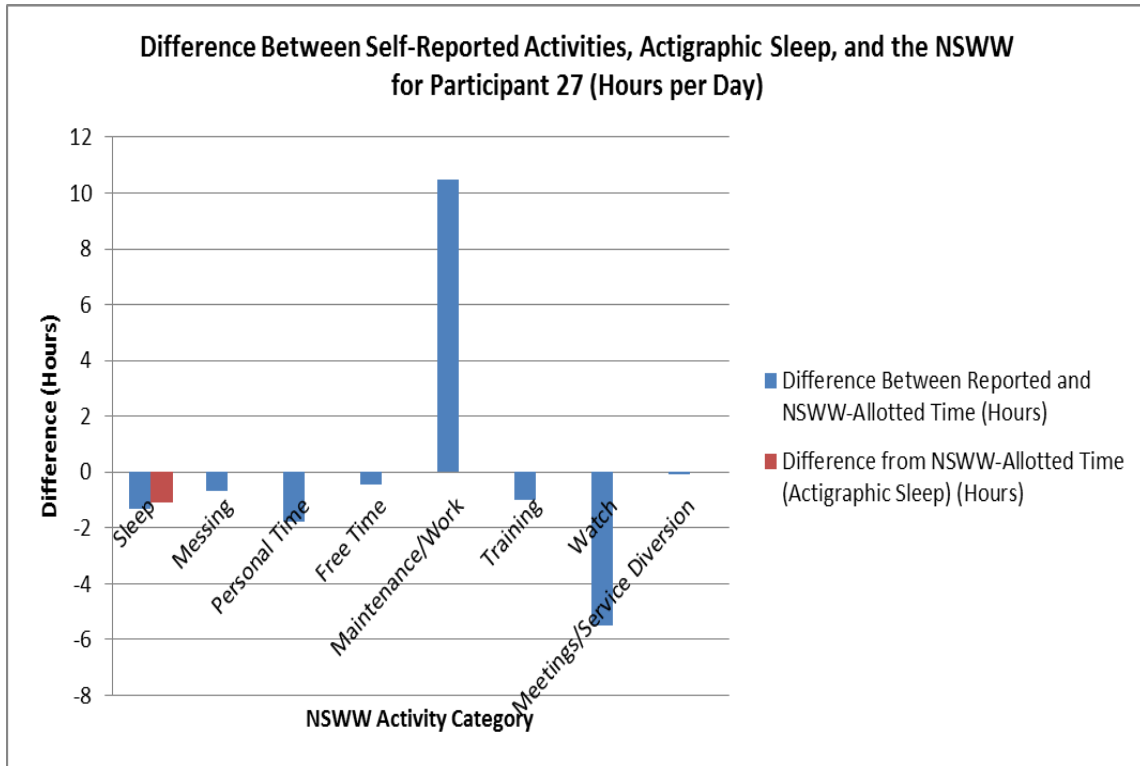
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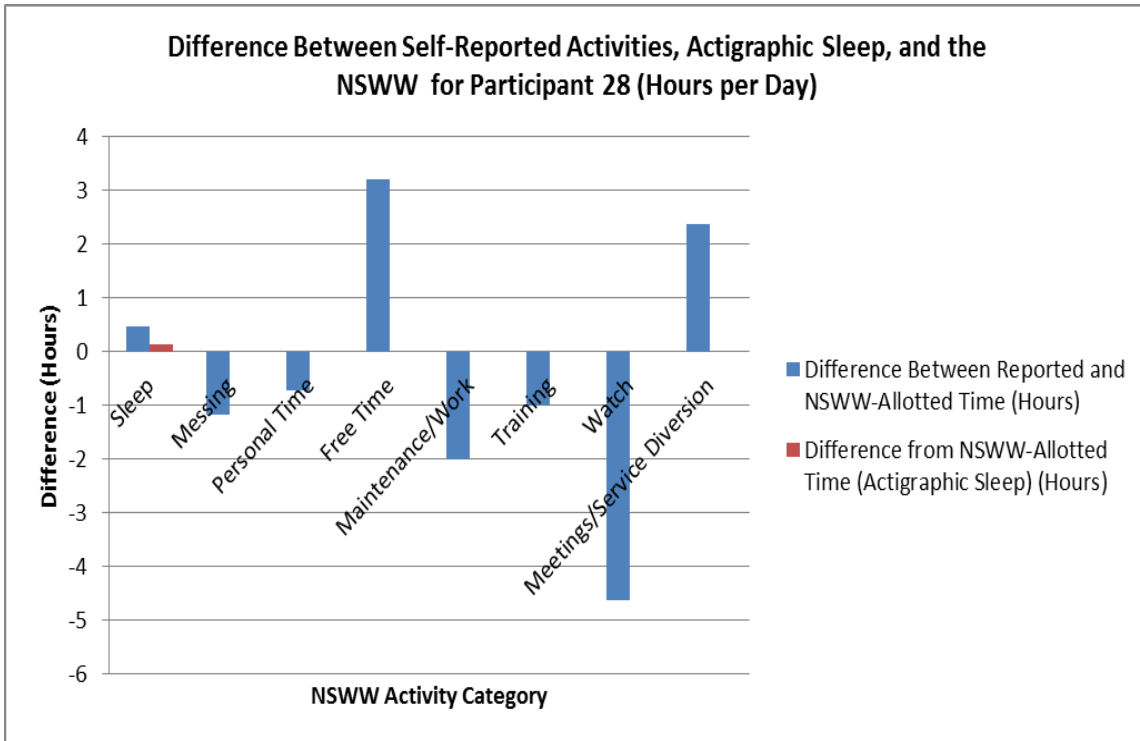
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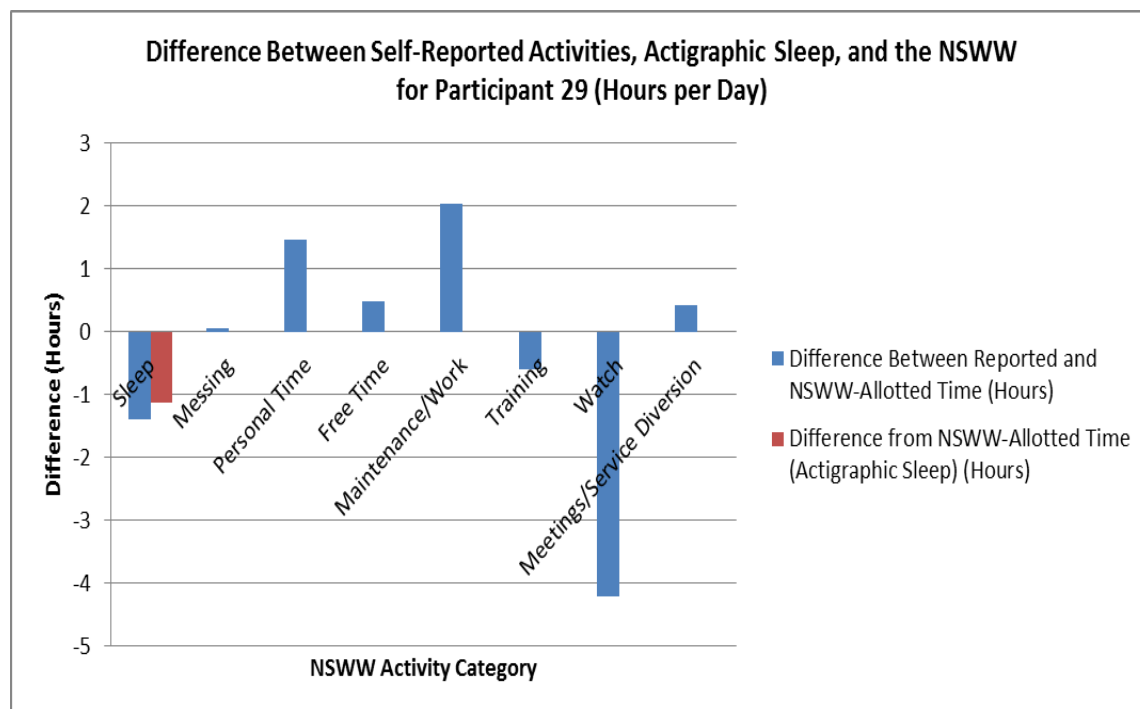
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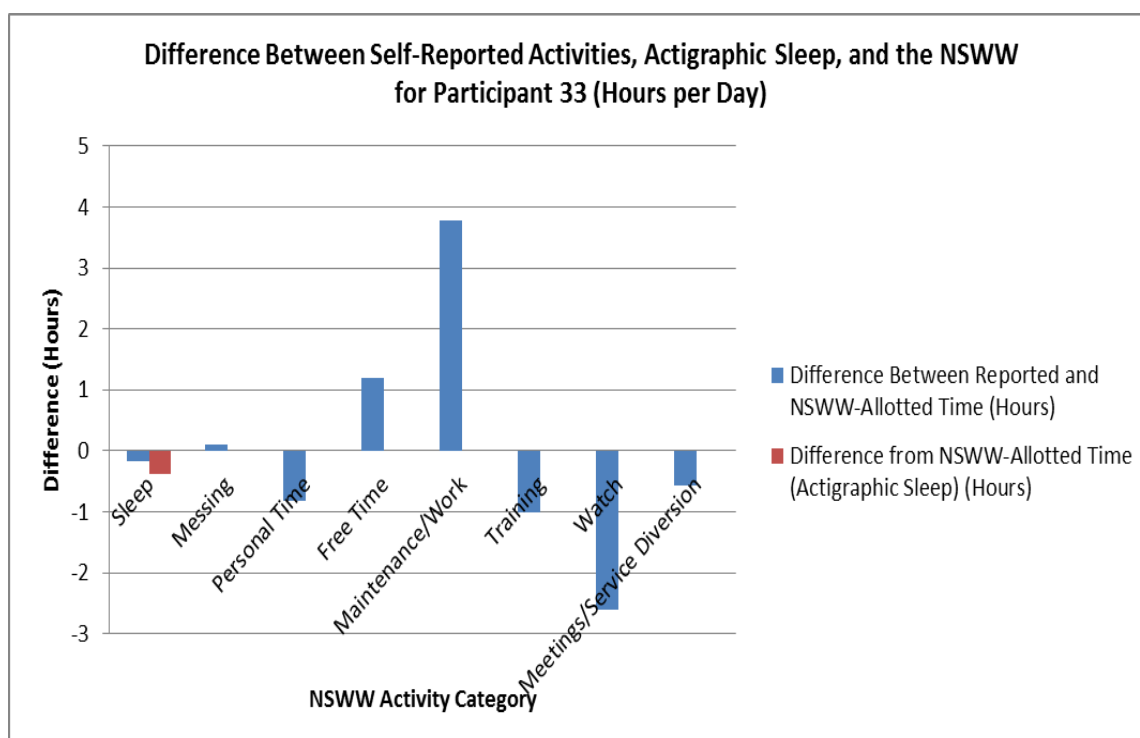
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Participant 33

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APPENDIX I.   INDIVIDUAL PARTICIPANT DEVIATION FROM THE NSWW
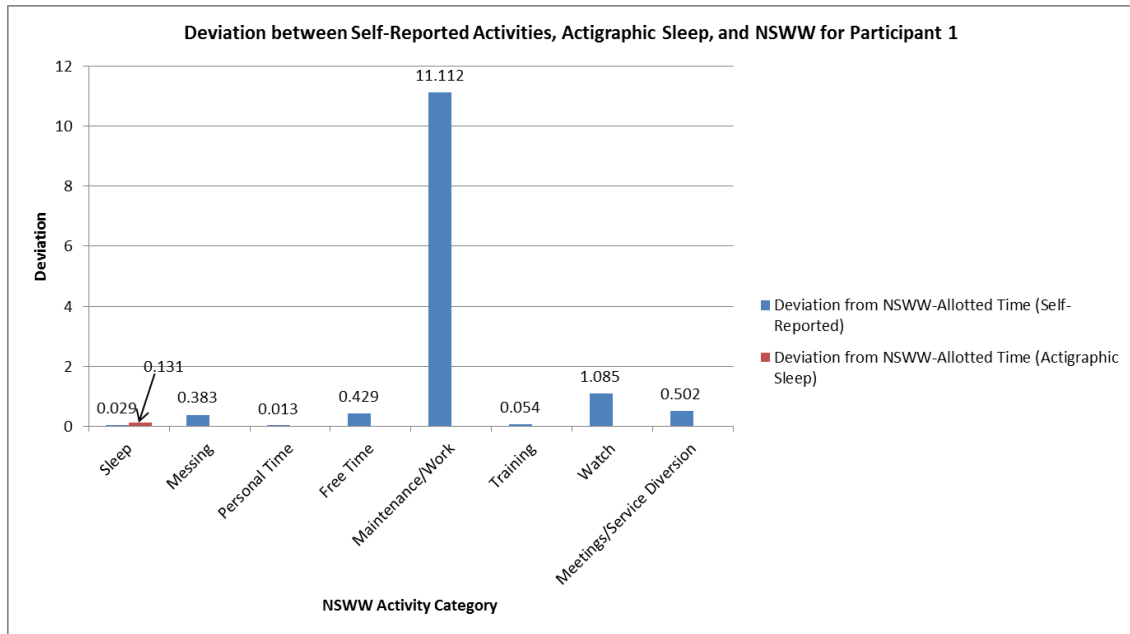
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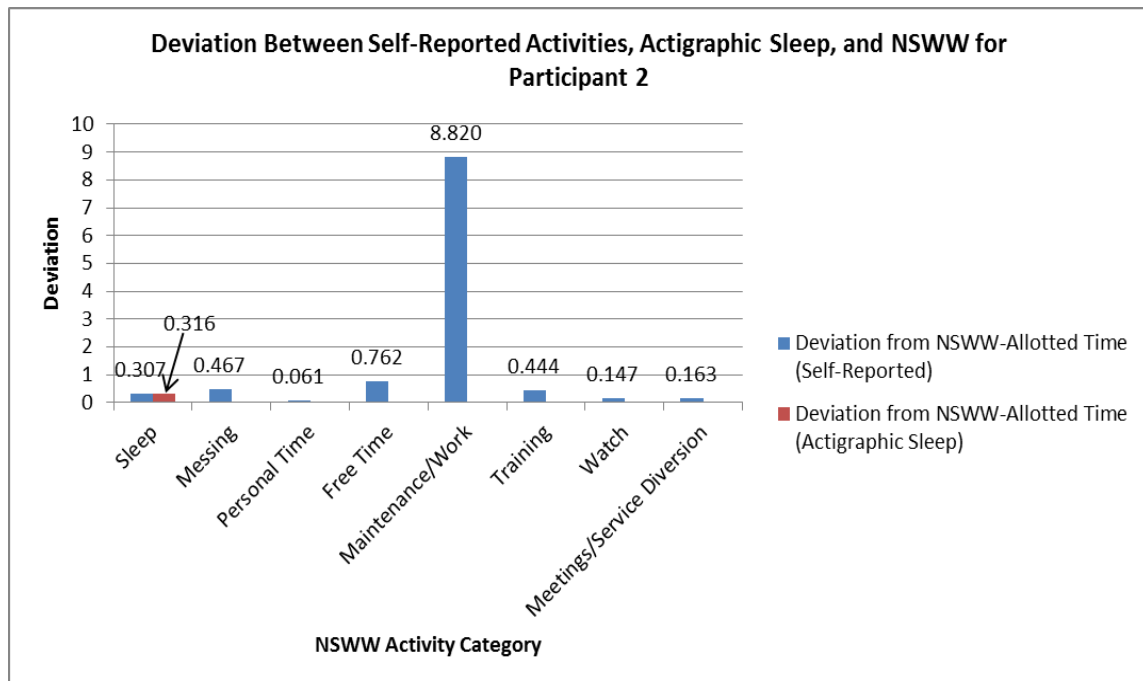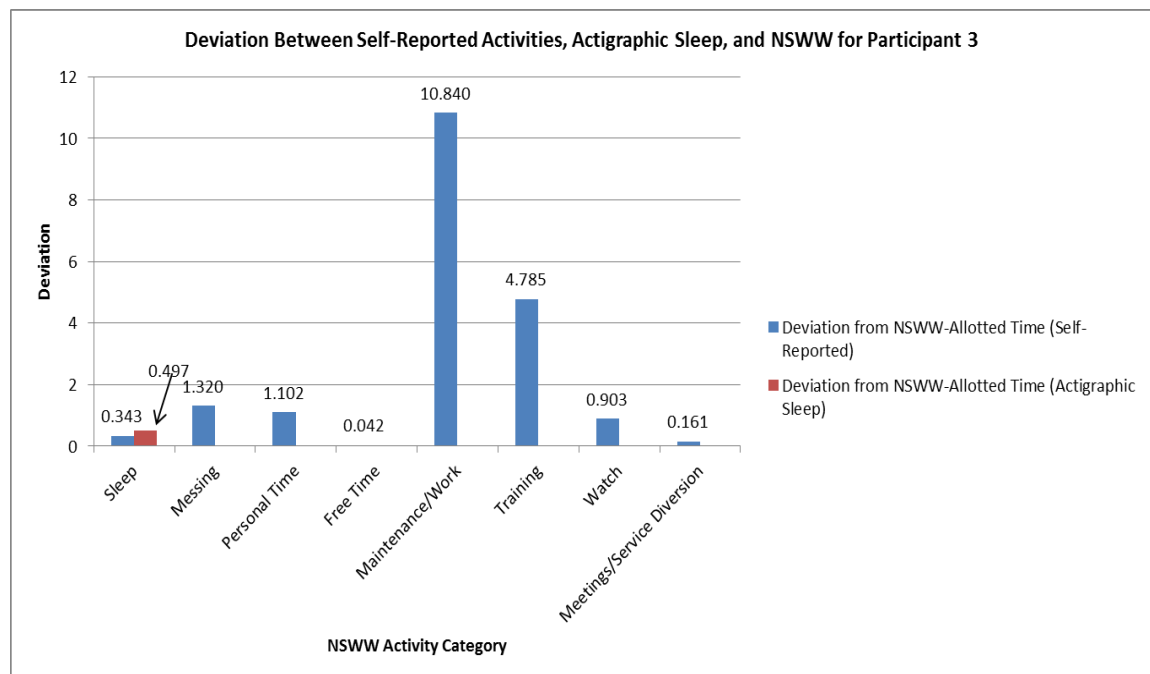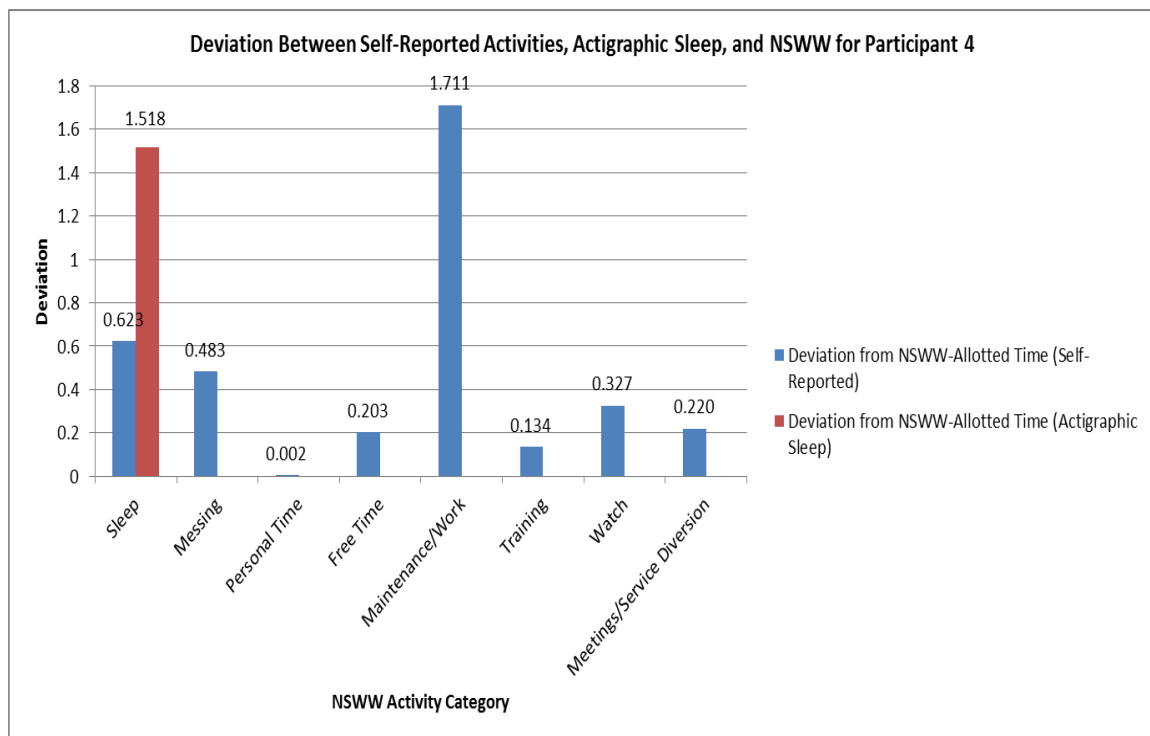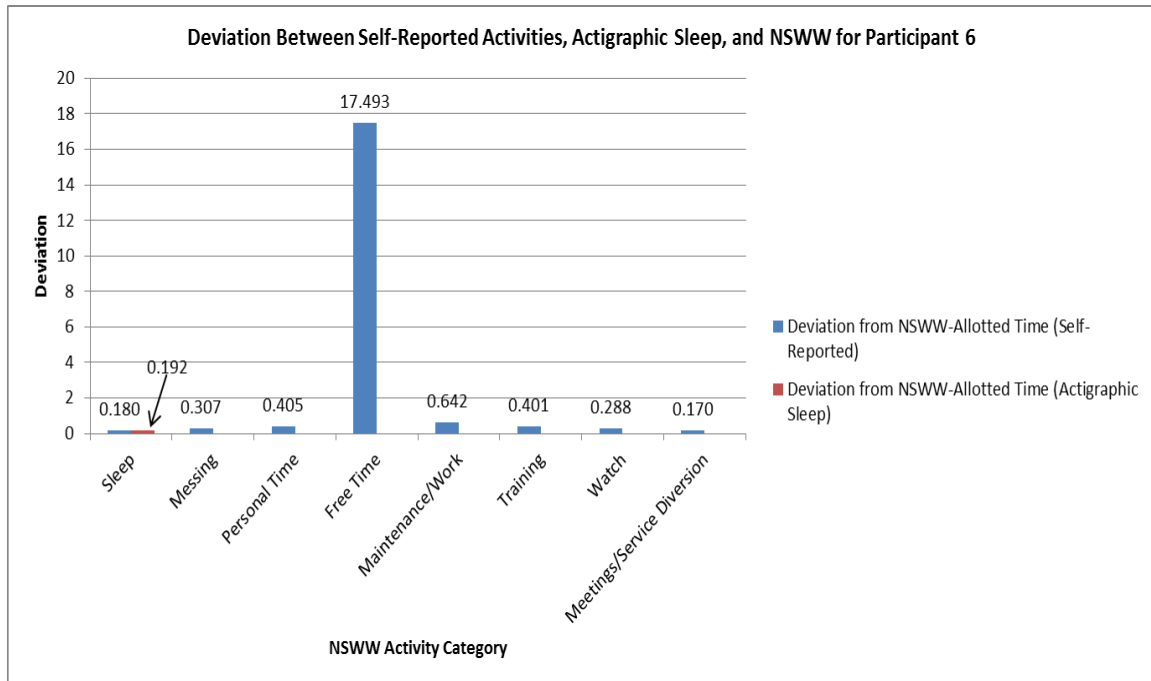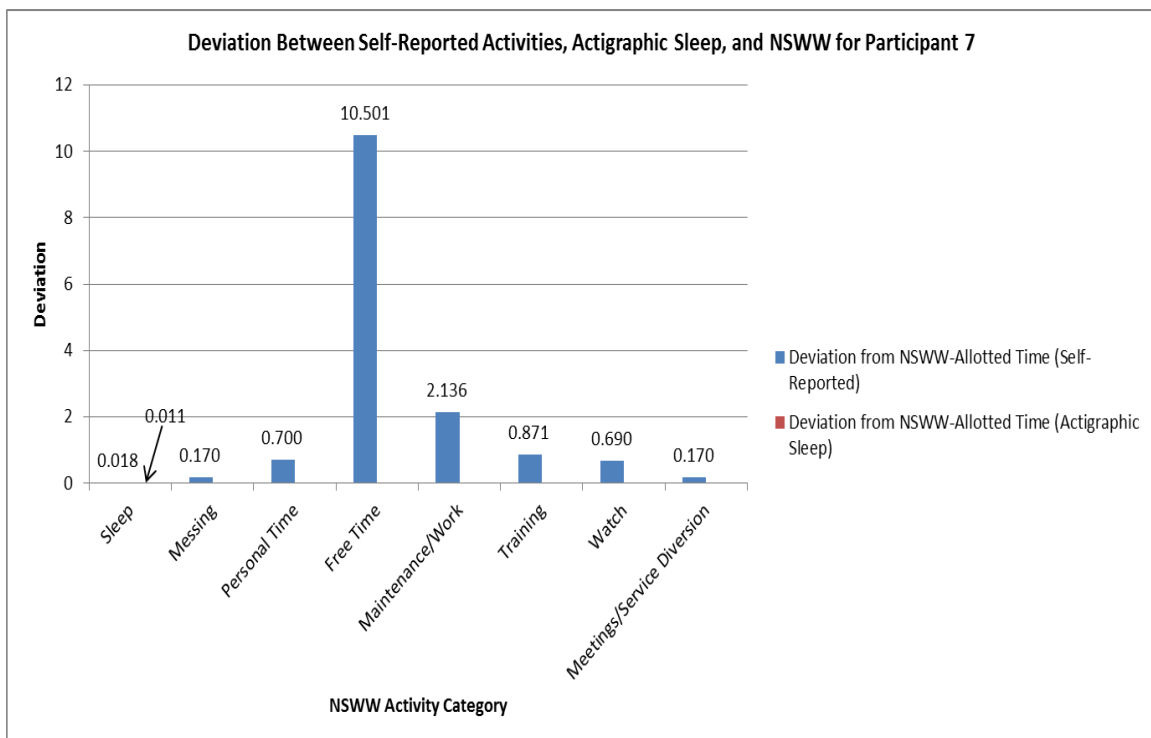
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Participant 3

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Participant 10

Participant 11

Participant 12

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Participant 13

Participant 15

Participant 16

Participant 17

Participant 18

Participant 20

Participant 21

Participant 22

Participant 23

Participant 24

Participant 25

Participant 26

Participant 27

Participant 28

Participant 29

Participant 33
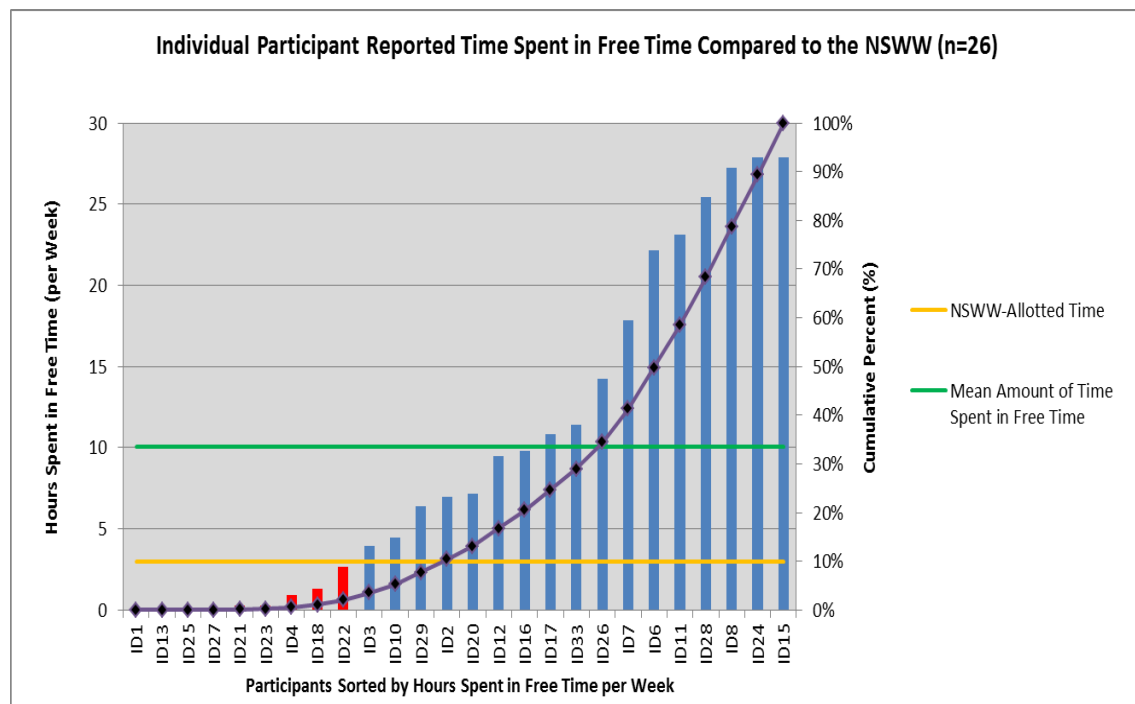
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Individual Participant Actigraphic Sleep Compared to the NSWW (n = 26)

Individual Participant Reported Time Spent in Messing Compared to the NSWW (n=26)

255

Individual Participant Reported Time Spent in Personal Time Compared to the NSWW (n=26)

Individual Participant Reported Time Spent in Free Time Compared to the NSWW (n=26)

Individual Participant Reported Time Spent Completing Maintenance/Work Compared to the NSWW (n = 26)

Individual Participant Reported Time Spent in Training Compared to the NSWW (n=26)

257

Individual Participant Reported Time Spent in Meetings/Service Diversion Compared to the NSWW (n=26)

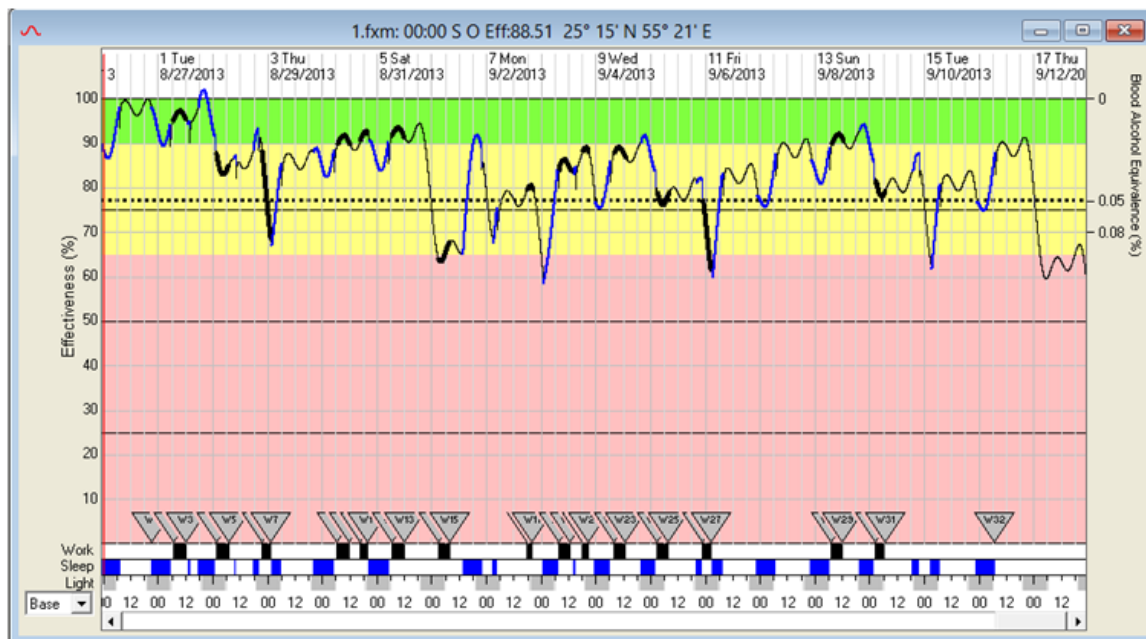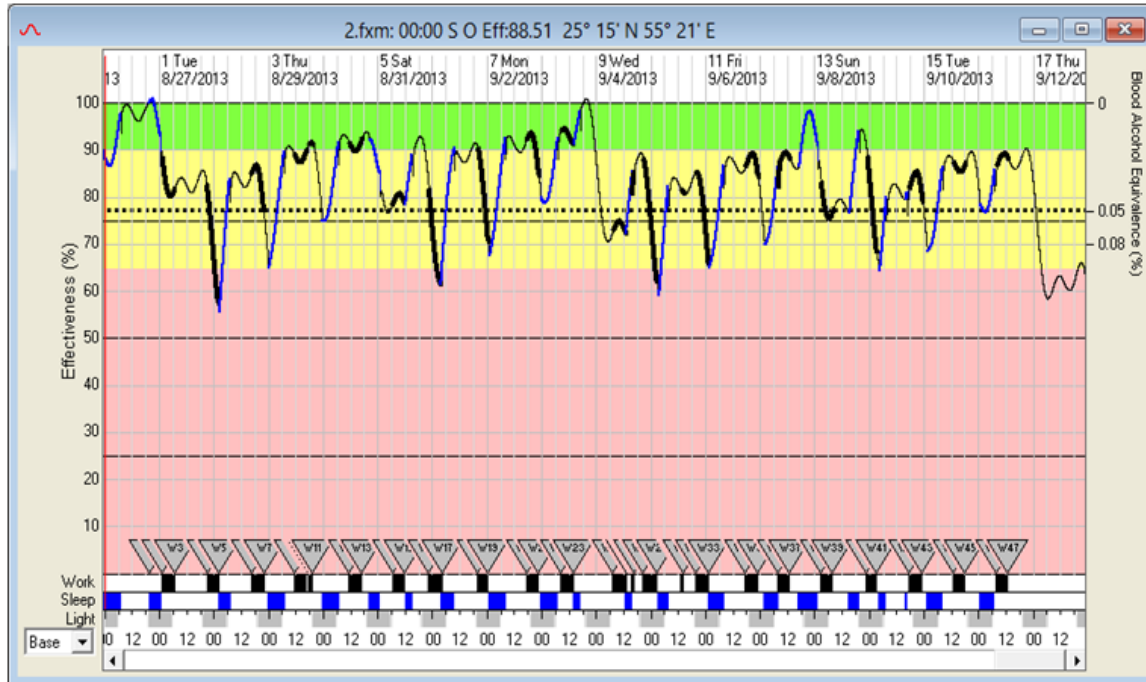Individual Participant Reported Time Spent in Meetings/Service Diversion Compared to the NSWW (n=26)
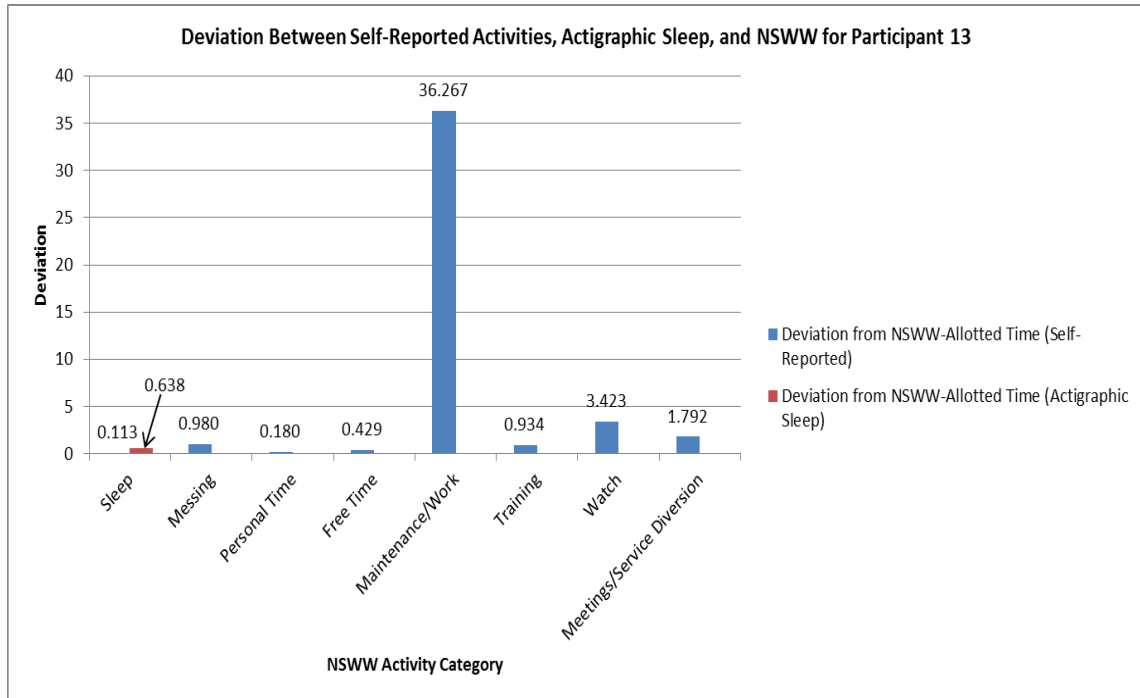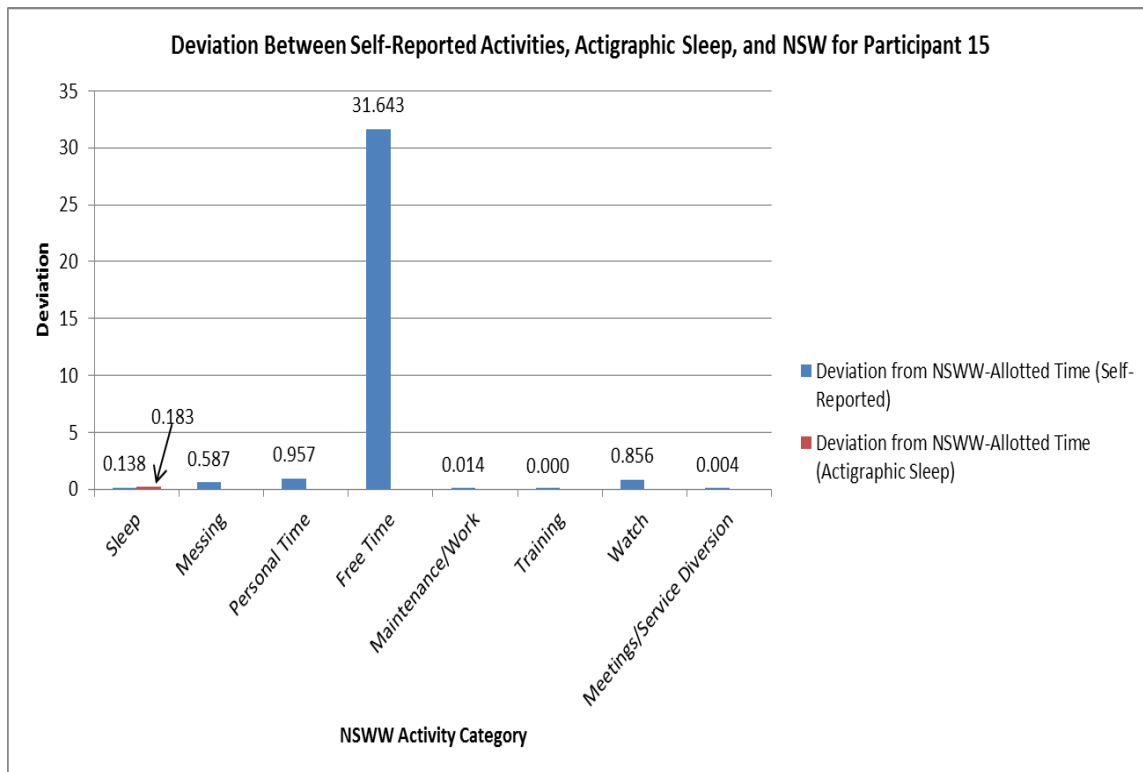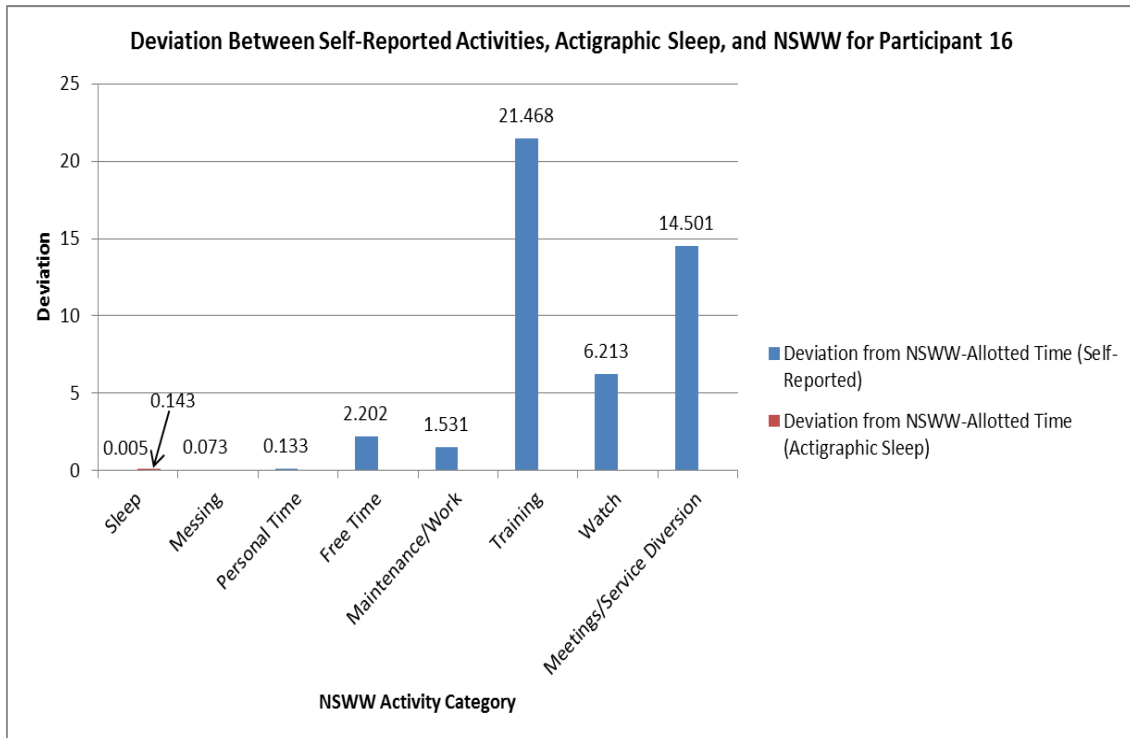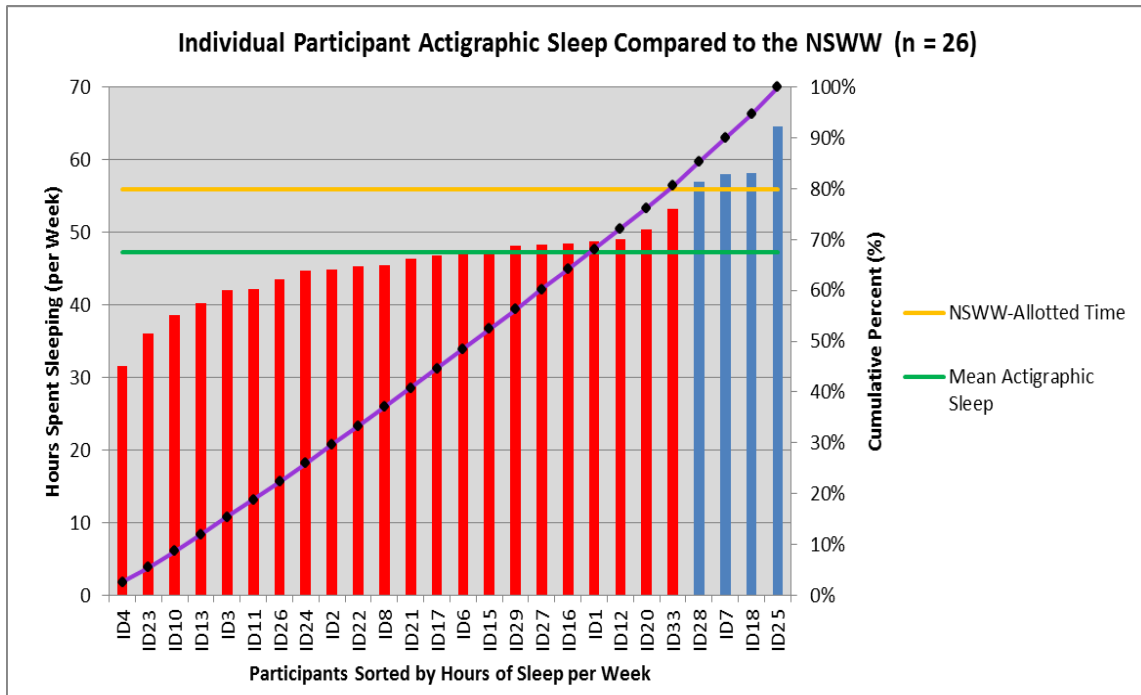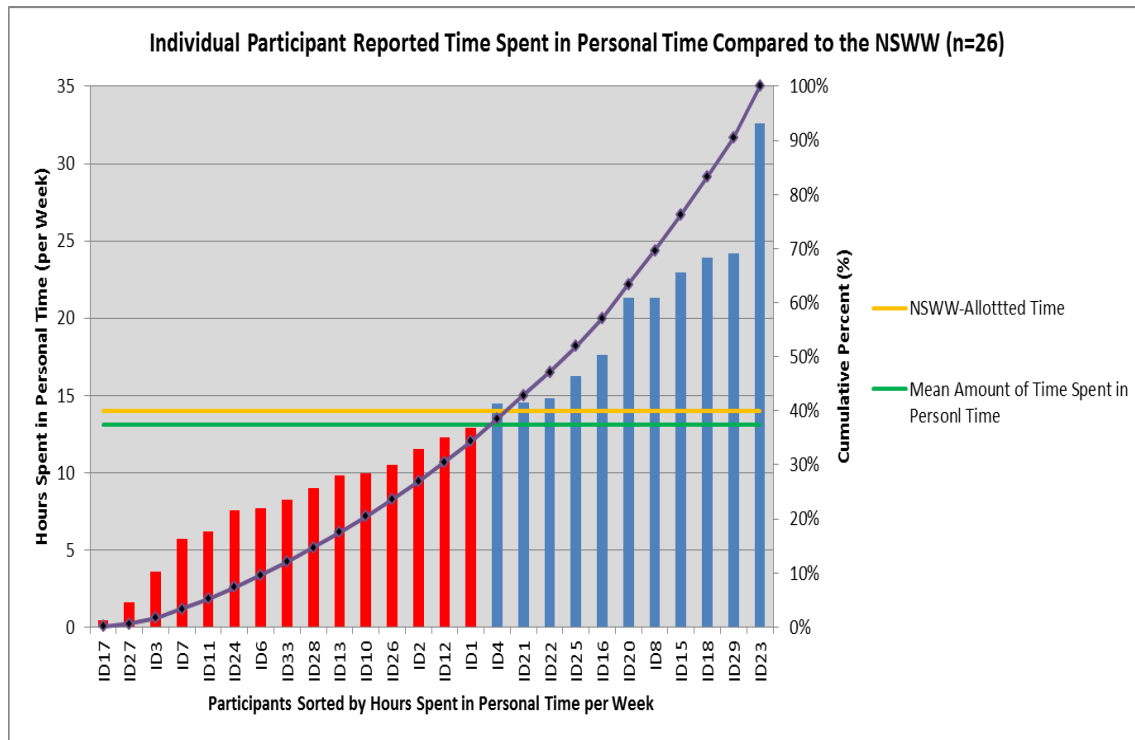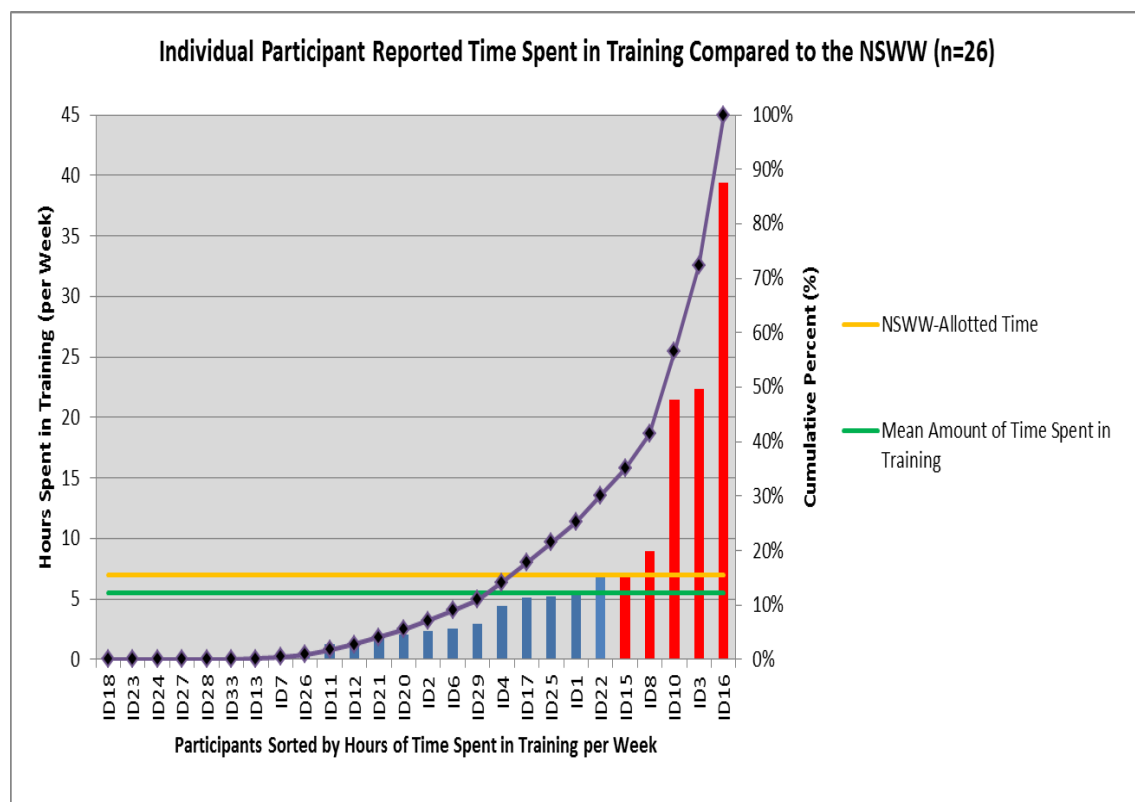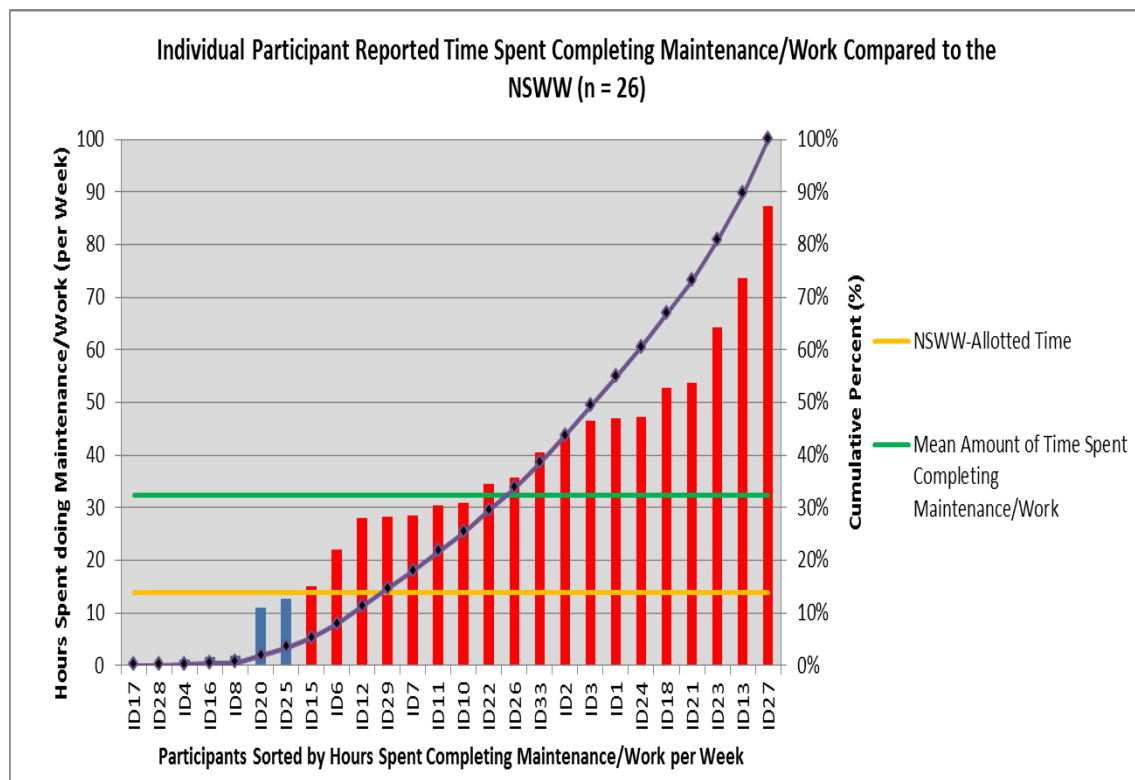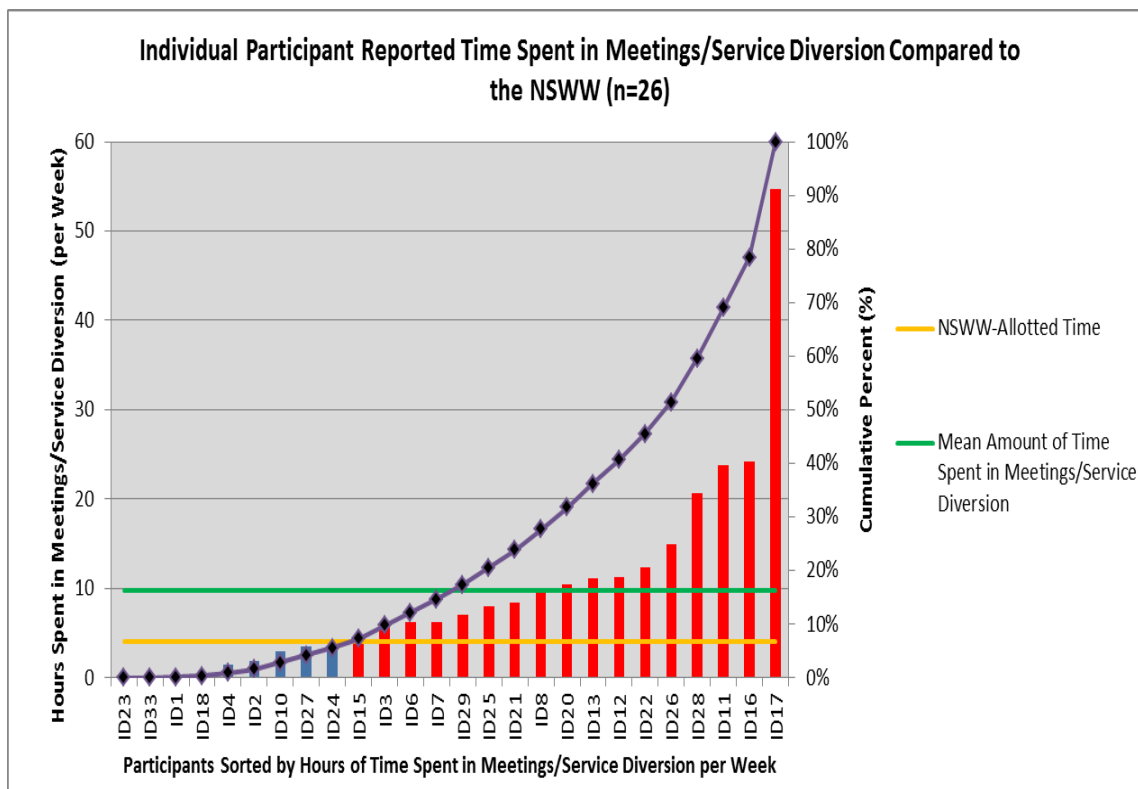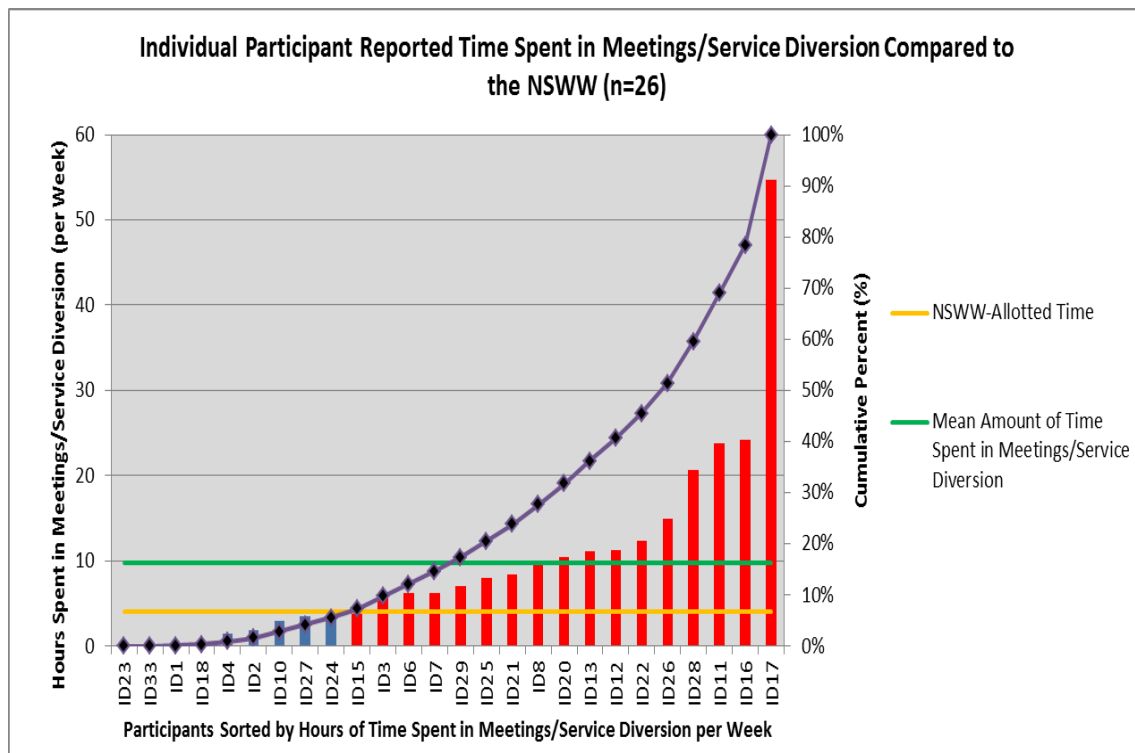
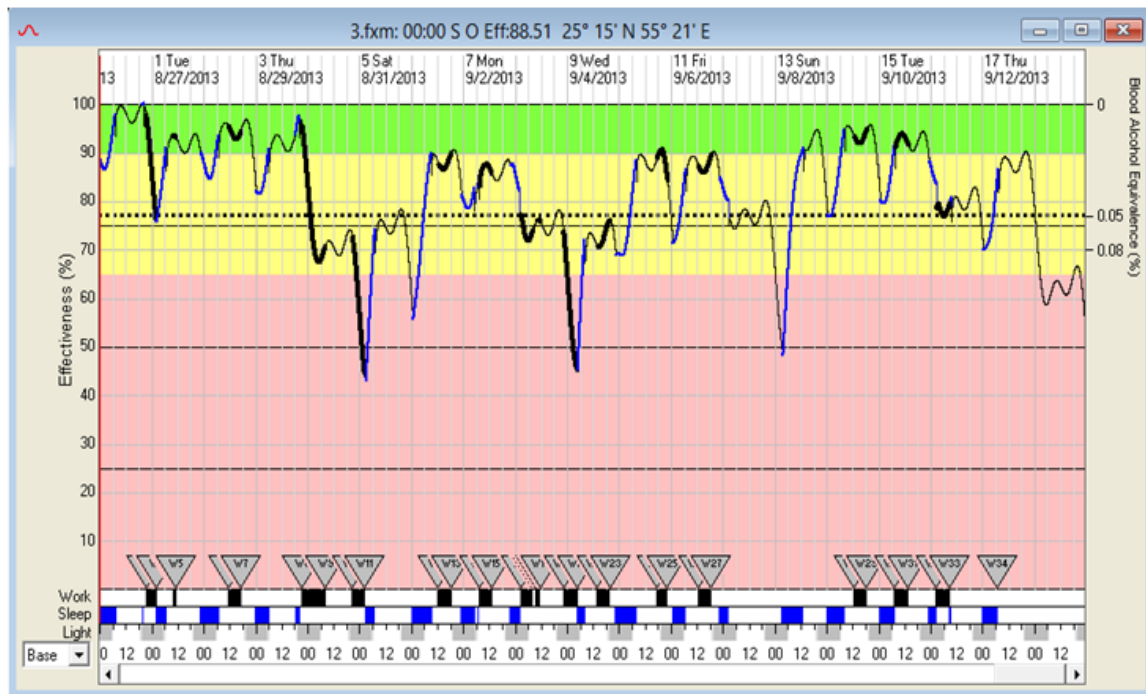# APPENDIX K.   INDIVIDUAL PARTICIPANT FAST PLOTS

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ID 3

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ID 11

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ID 12

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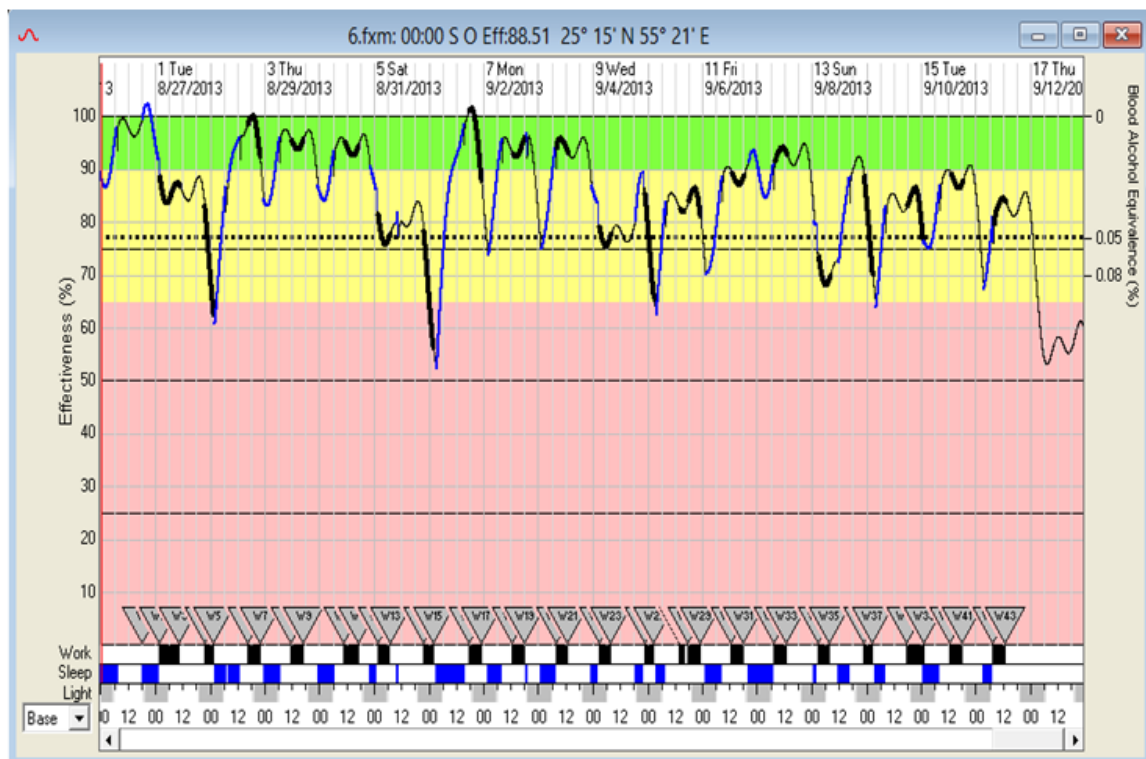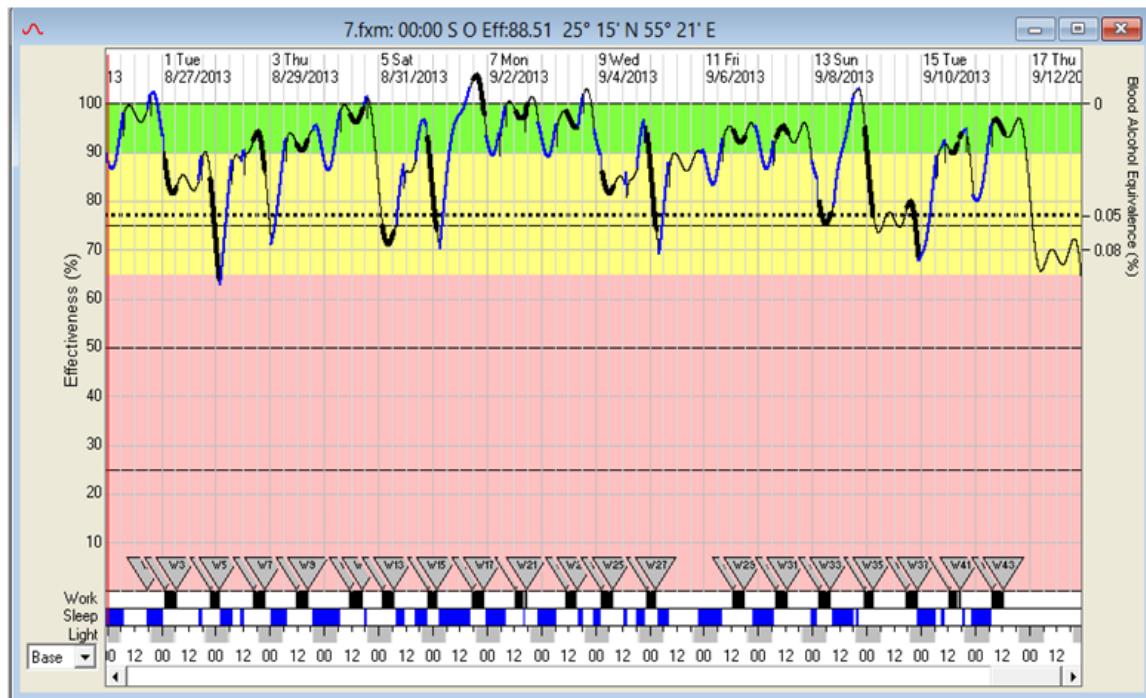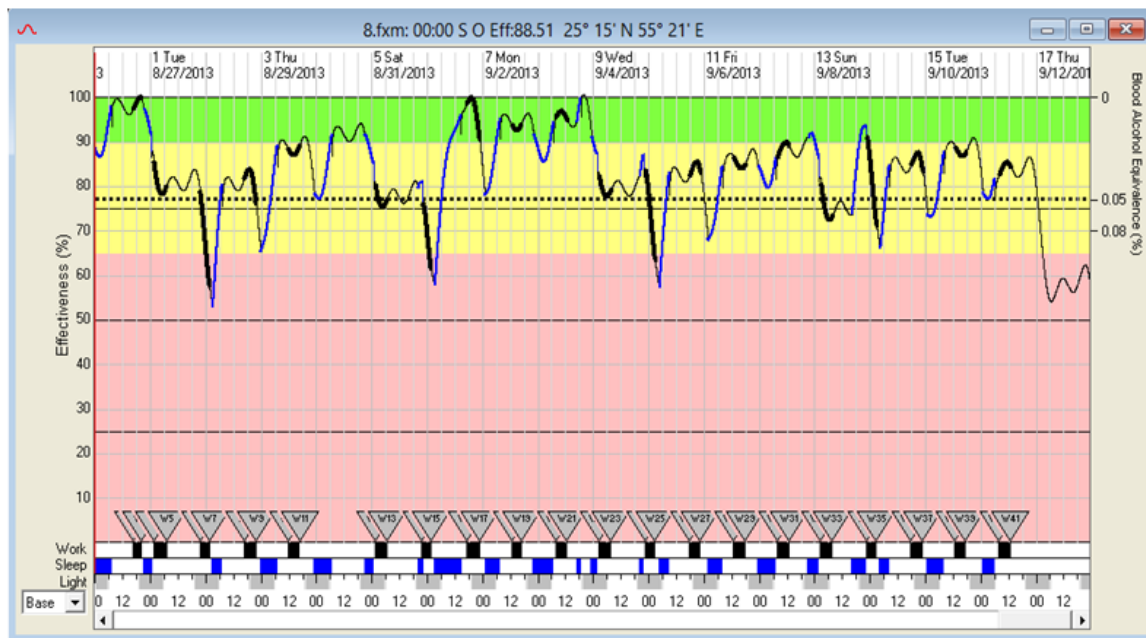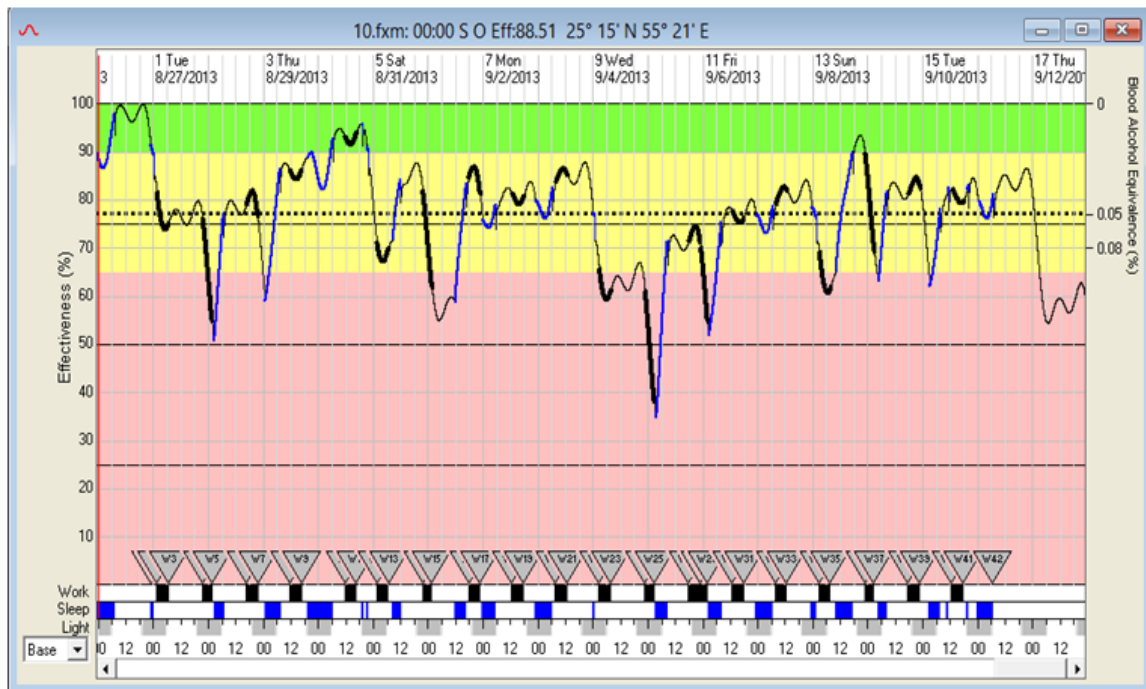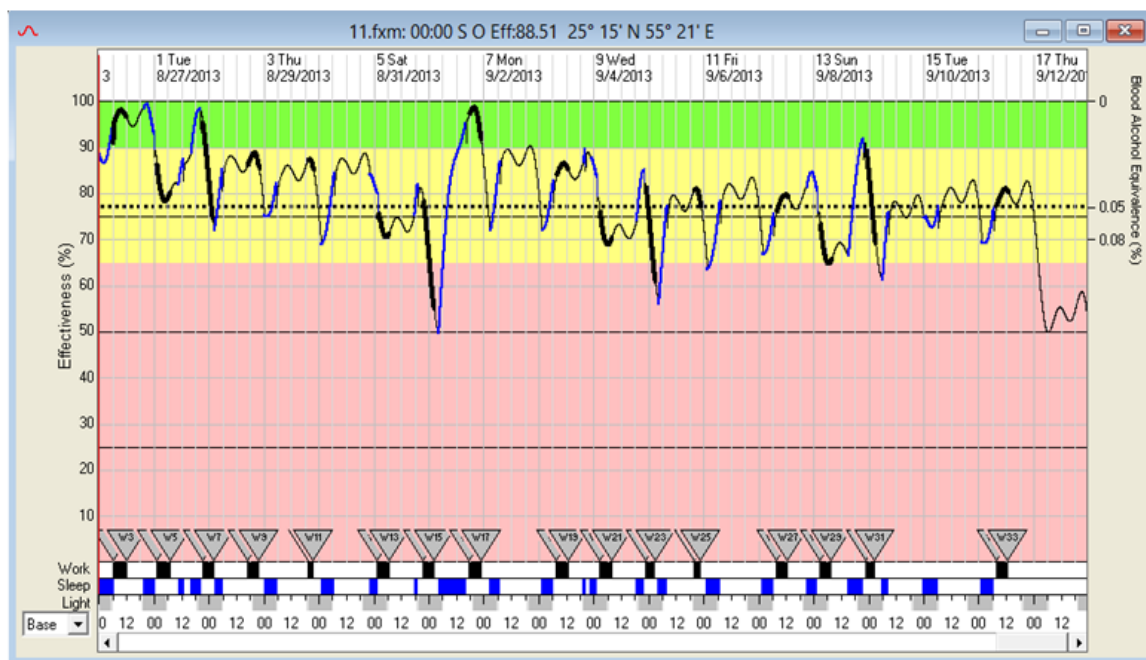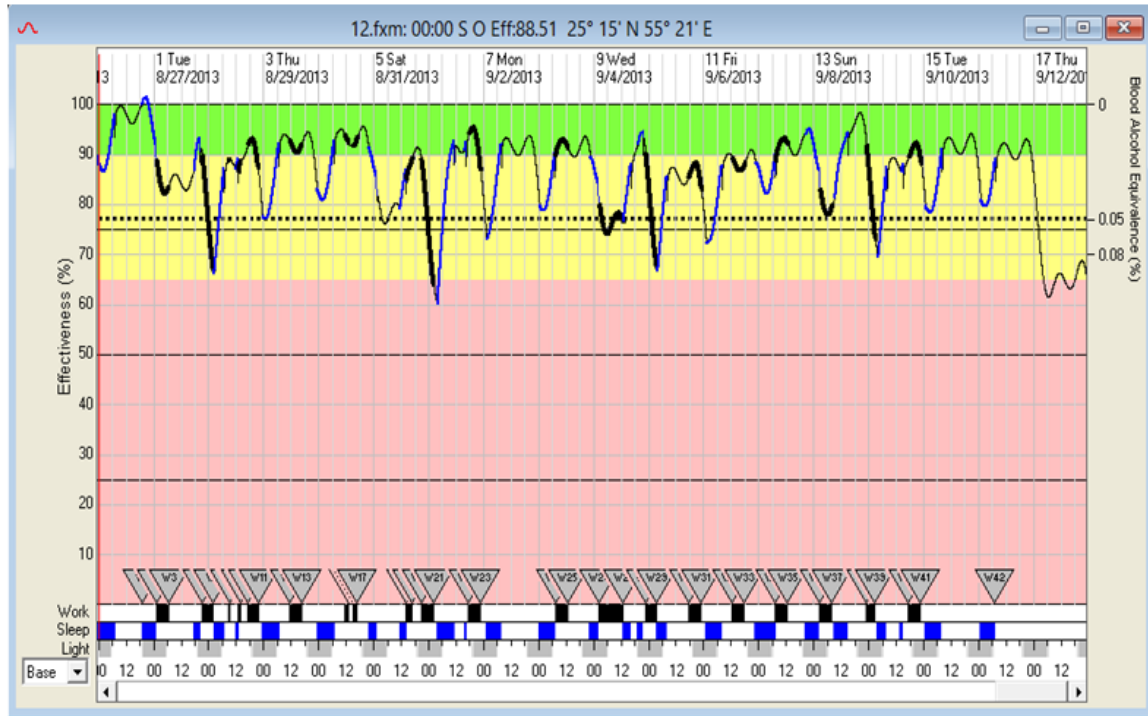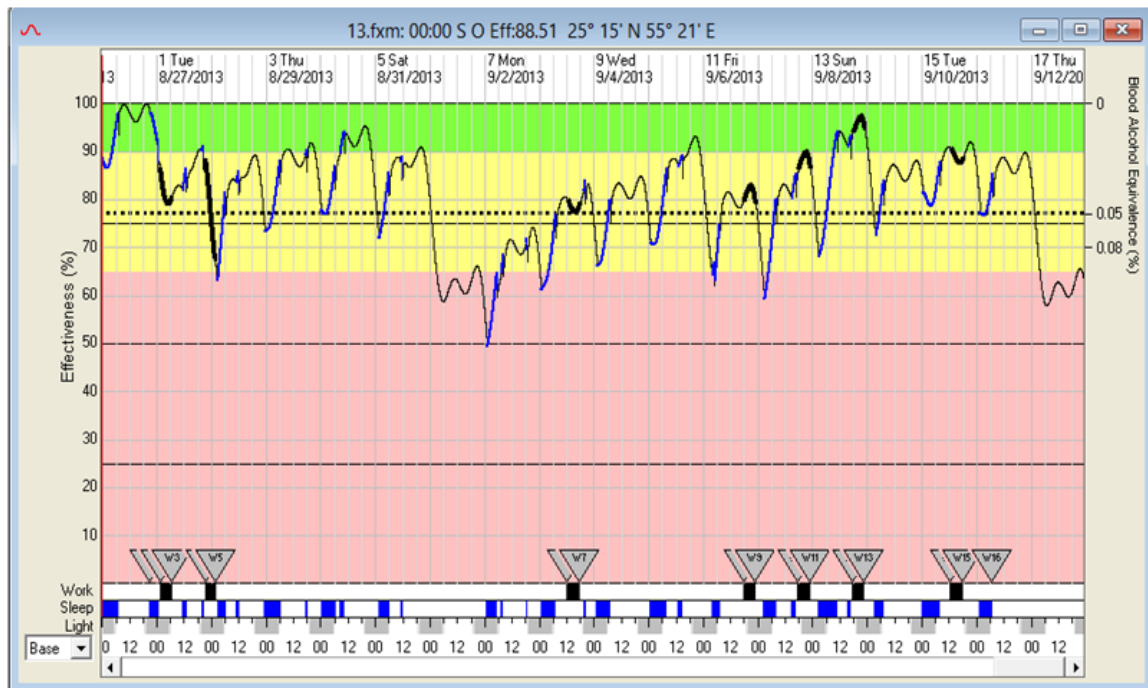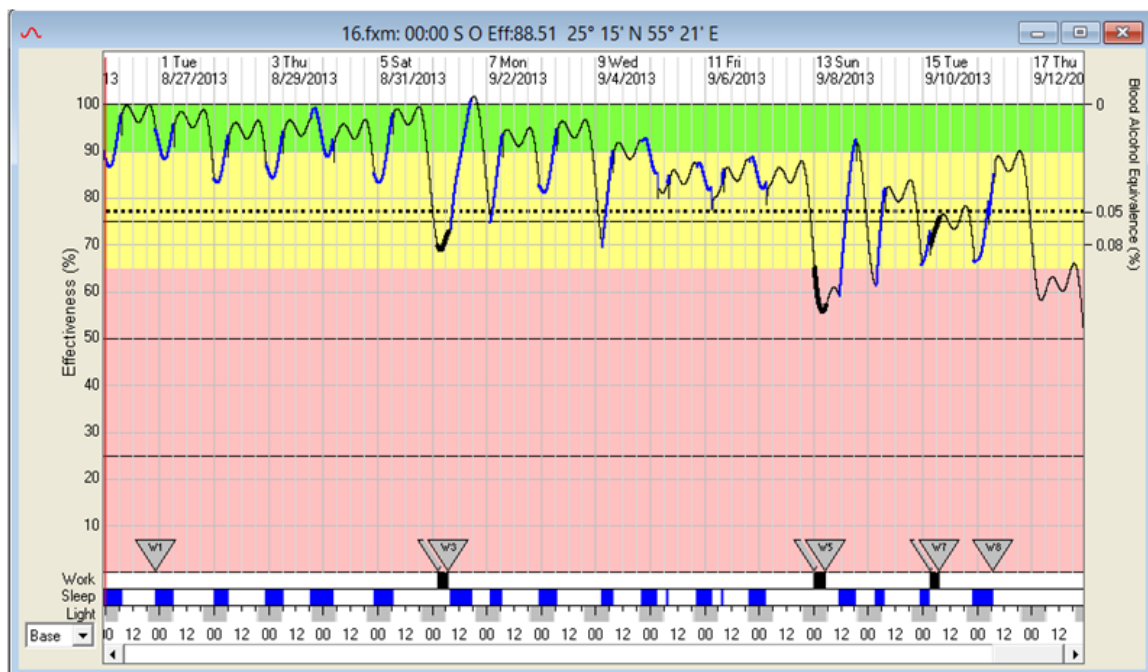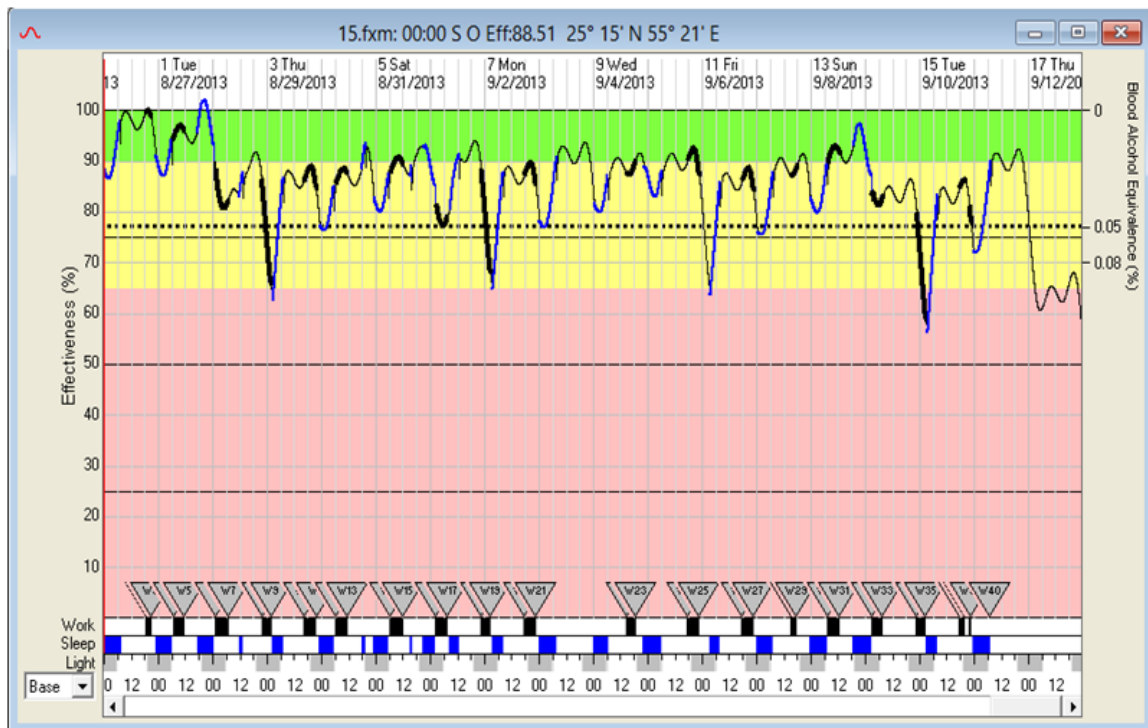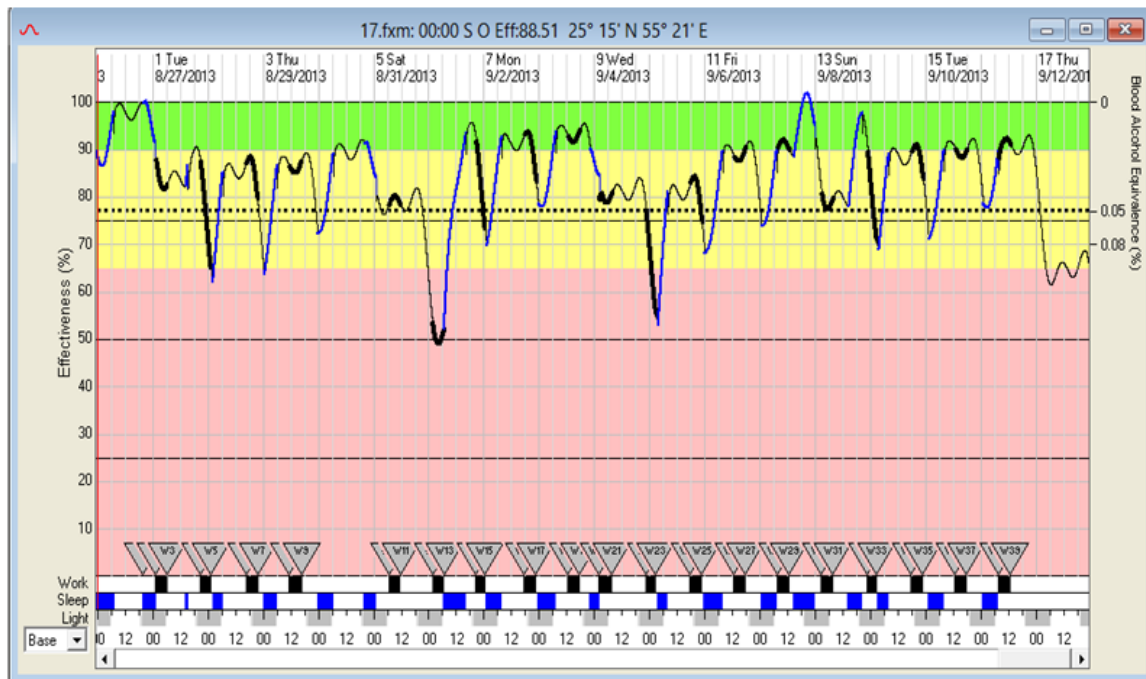
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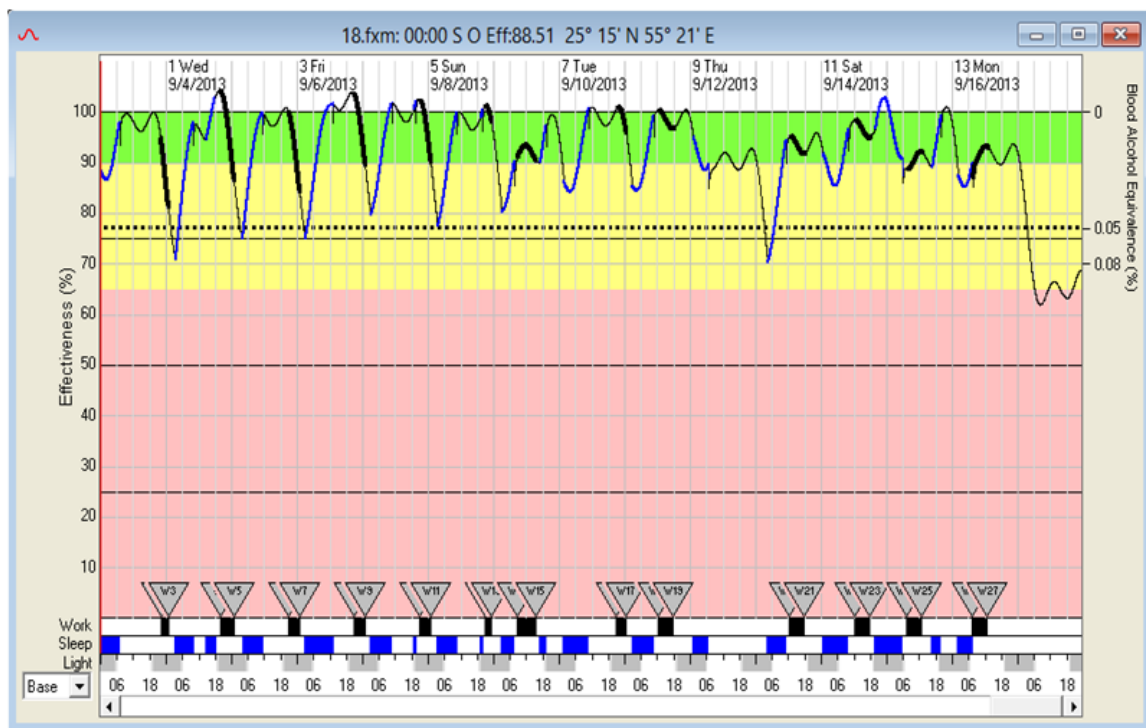
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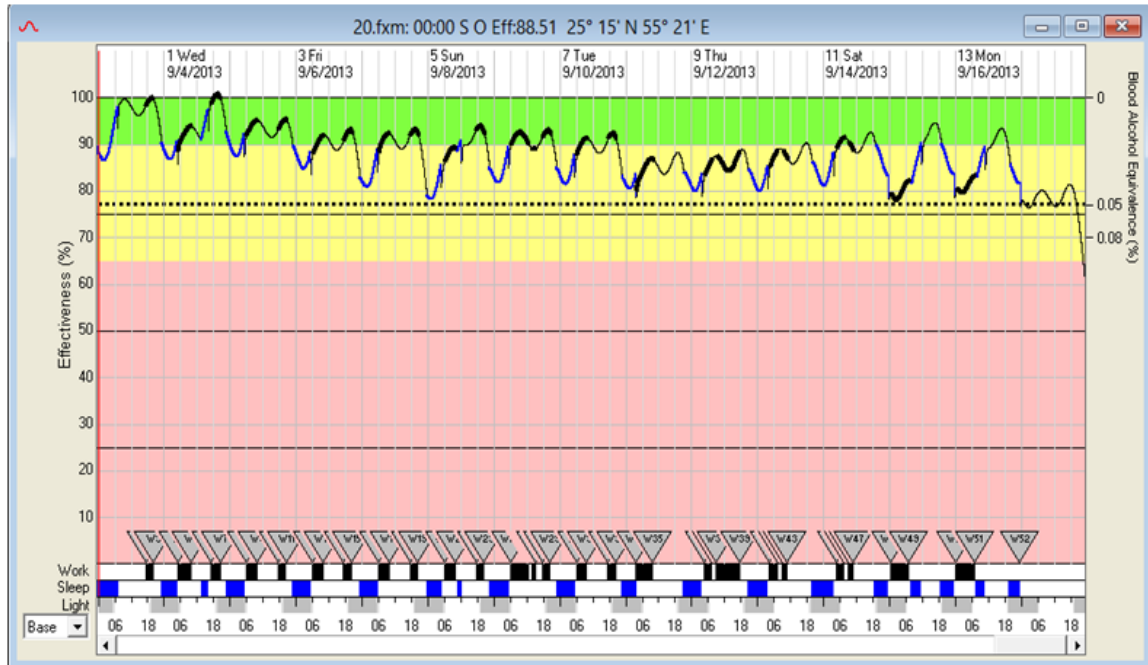
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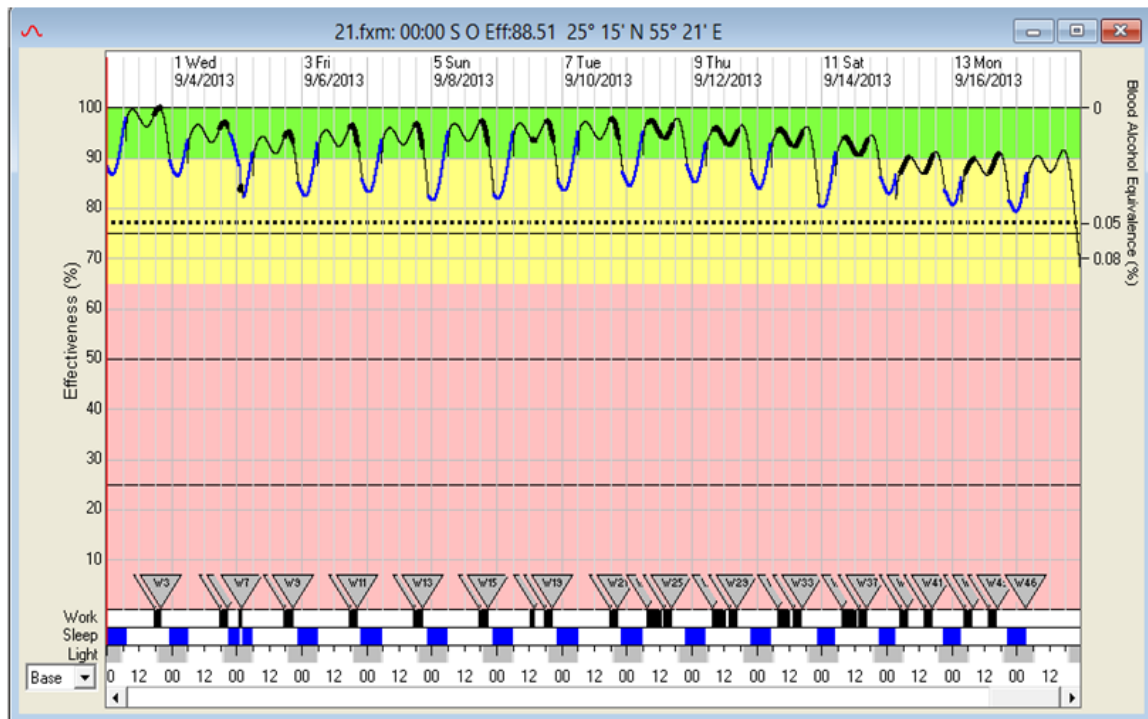
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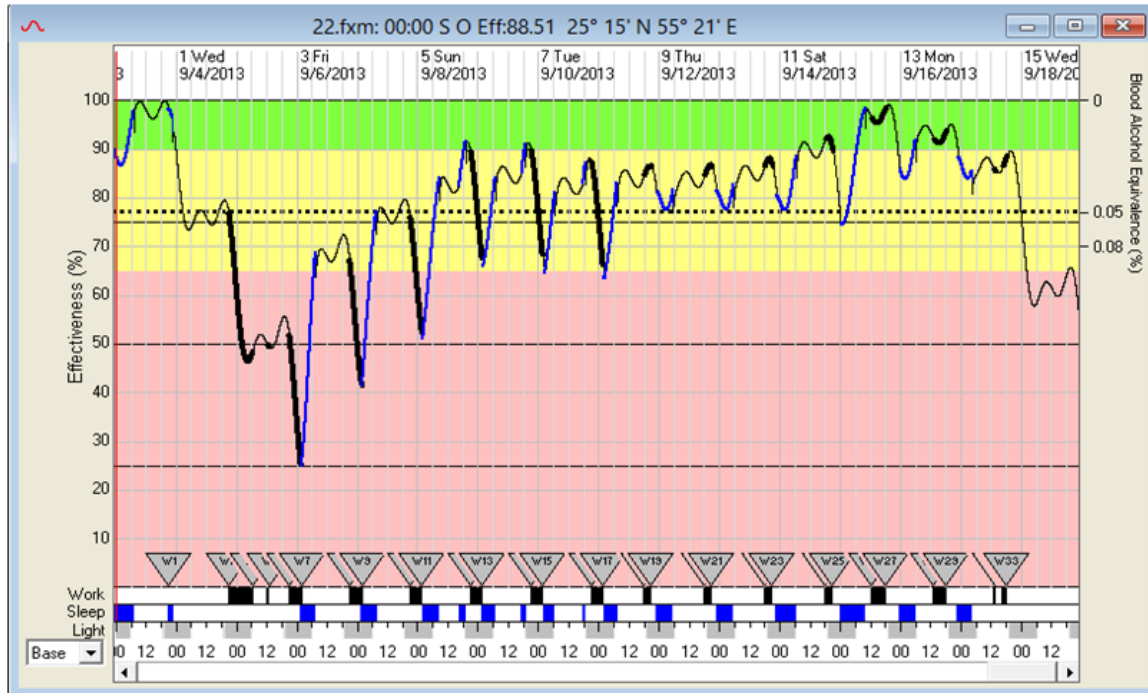
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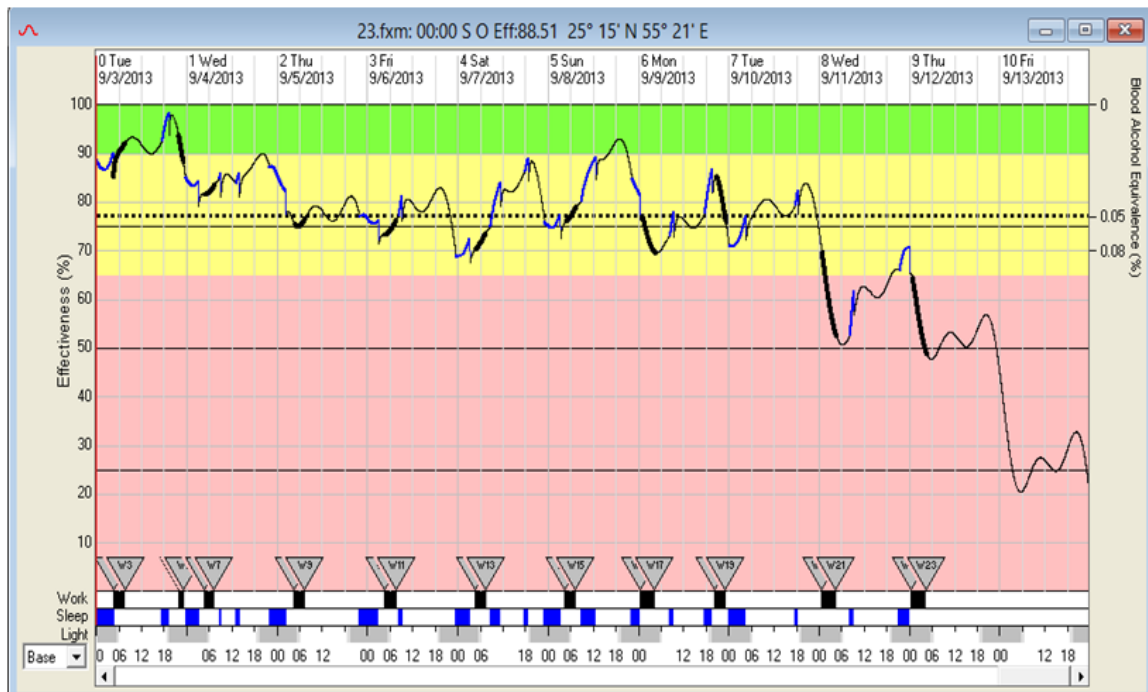
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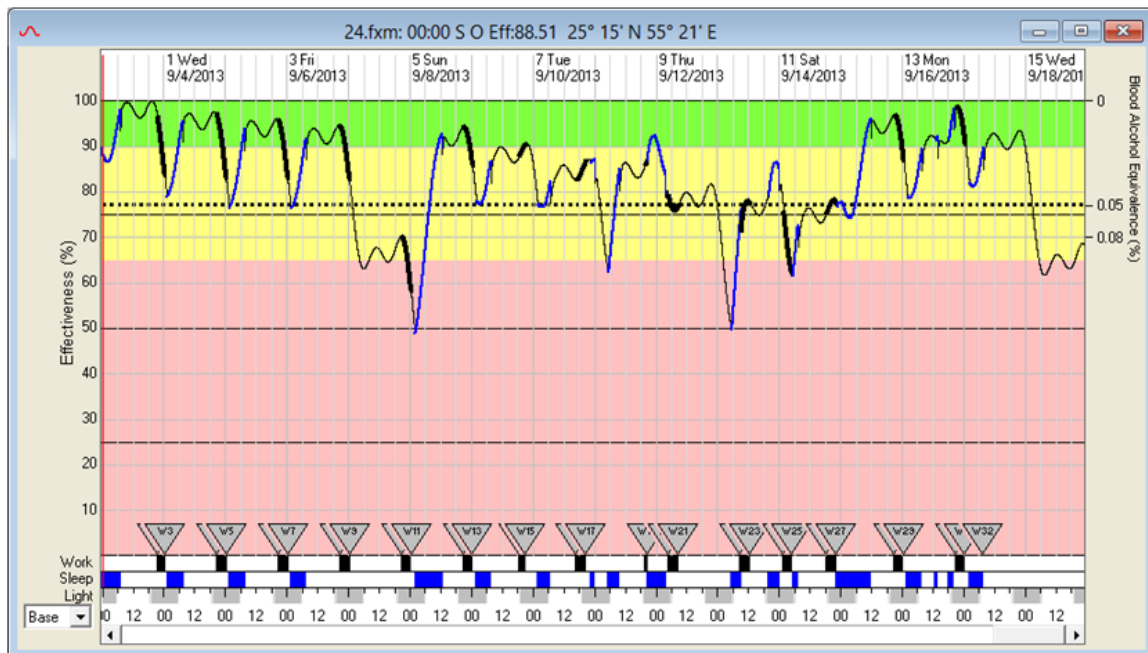
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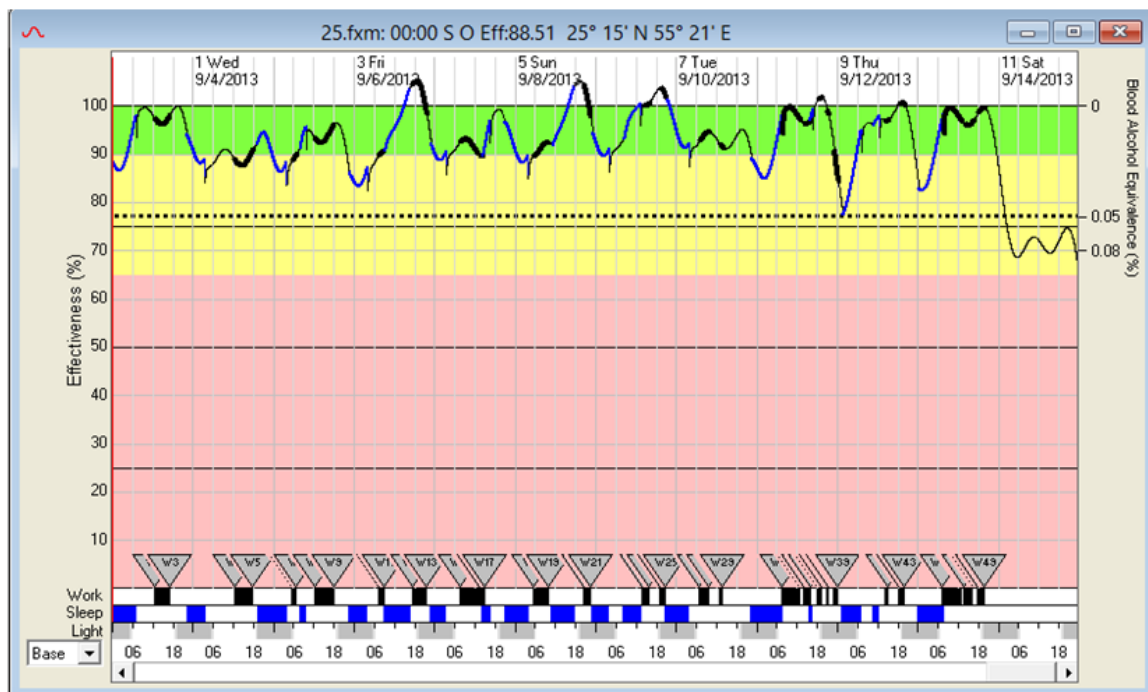
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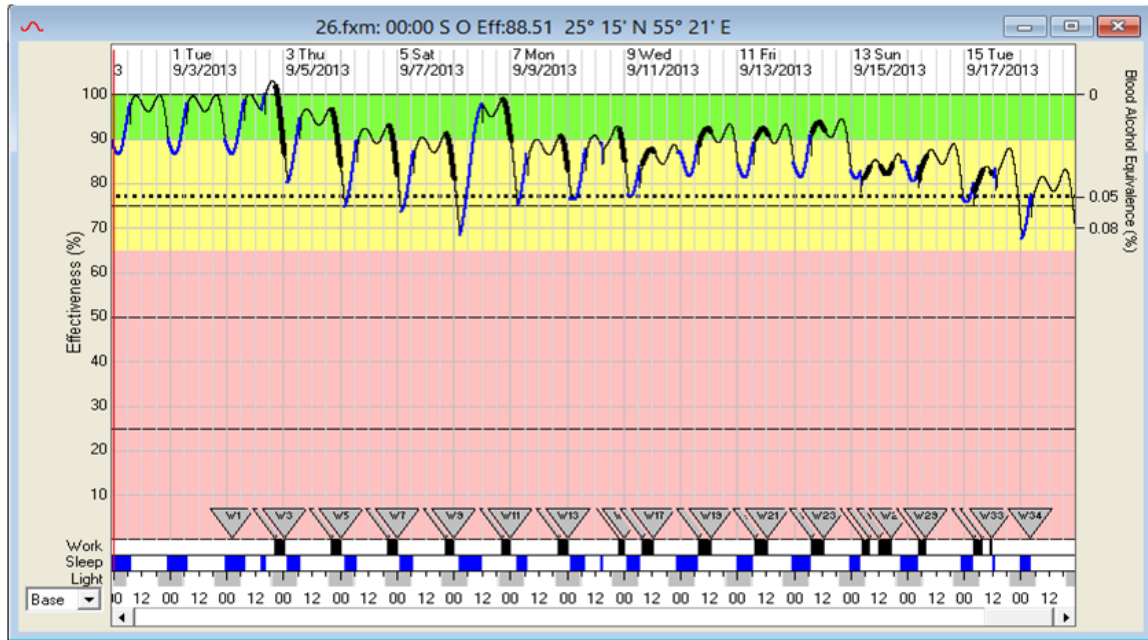
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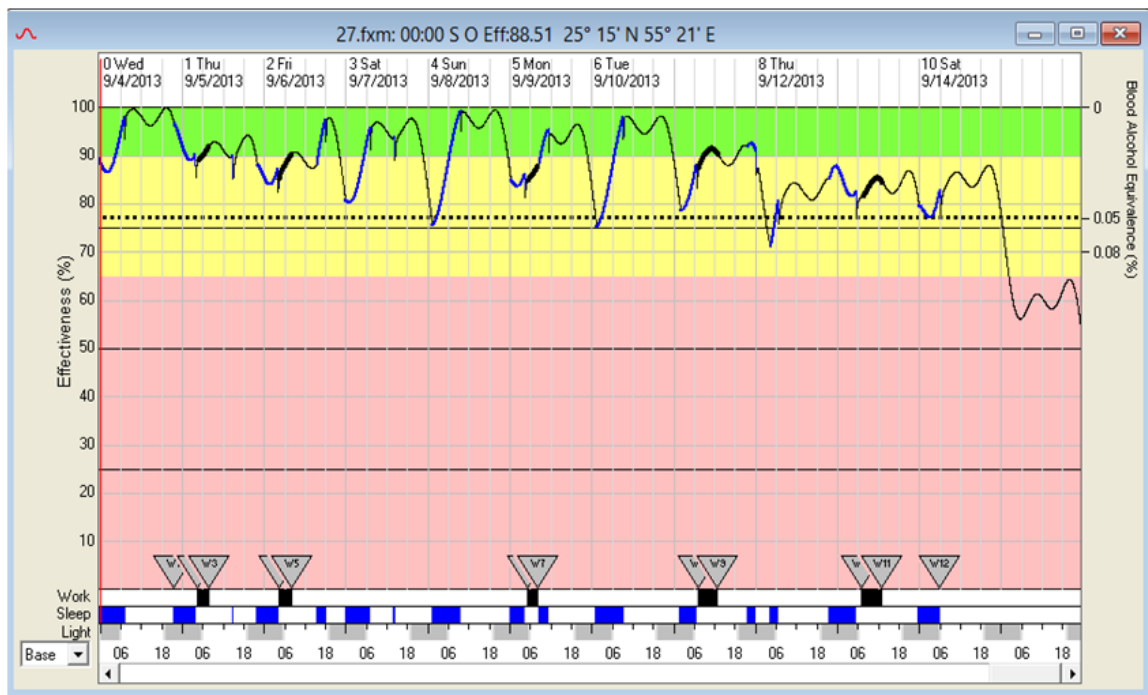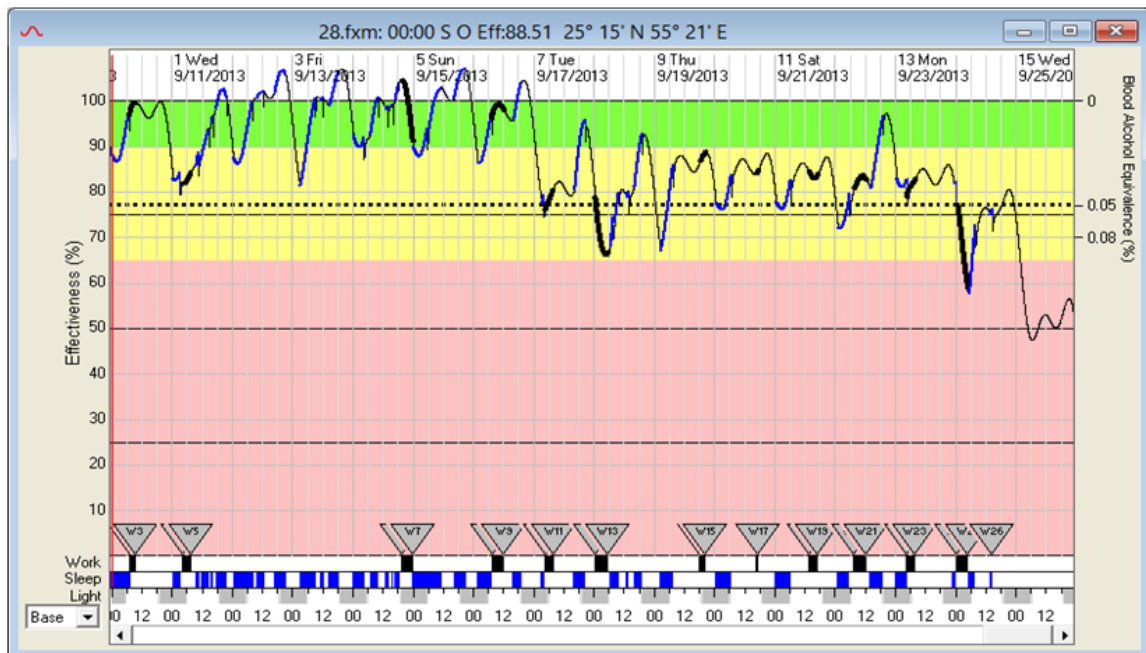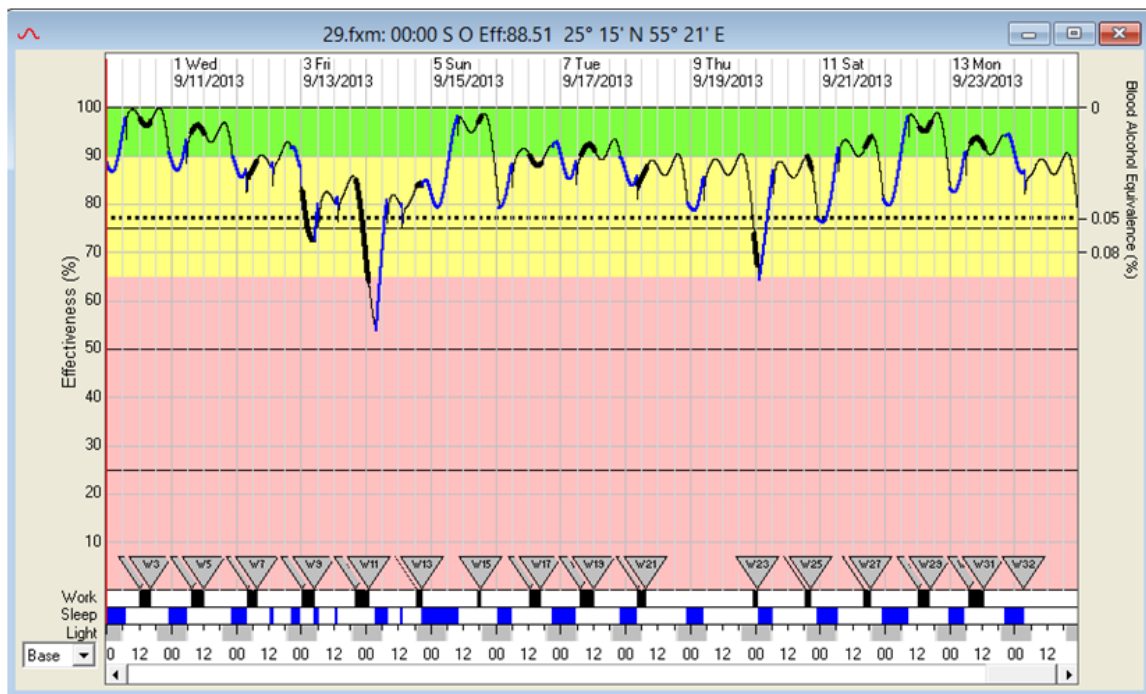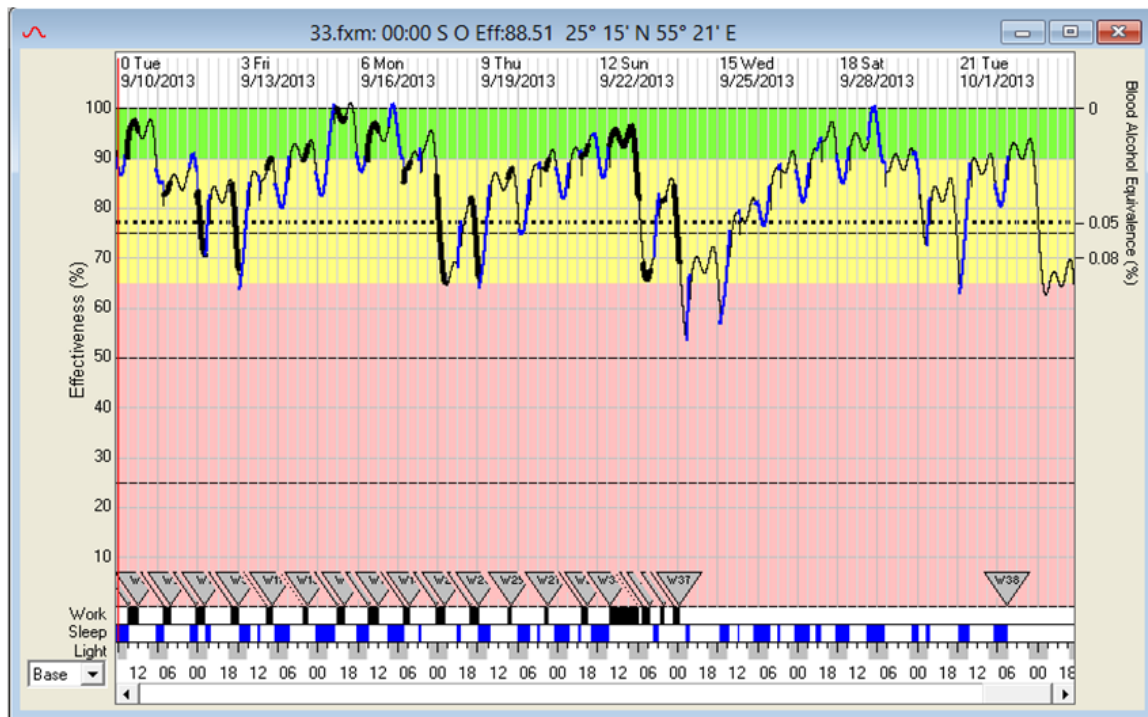
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LIST OF REFERENCES

Achermann, P., & Borbely, A. A. (1992). Combining different models of sleep regulation. *Journal of Sleep Research*, *1*(2), 144–177. doi: 10.1111/j.1365-2869.1992.tb00028.x

Akerstedt, T. (1988). Sleepiness as a consequence of shift work. *Sleep*, *11*(1), 17–34. Retrieved from http://www.journalsleep.org/ViewAbstract. aspx?pid=25135

Akerstedt T., & Folkard, S. (1995). Validation of the S and C components of the three-process model of alertness regulation. *Sleep*, *18*(1), 1–6.

Alion Science and Technology. (2013). Imprint pro user guide: Vol. 1, basic procedures. Boulder, CO: Alion Science and Technology.

Alion Science and Technology. (2014, April). IMPRINT Pro Training and User Meeting. Presented at Aberdeen Proving Grounds, Aberdeen, MD.

American Academy of Sleep Medicine. (2005). *The International Classification of Sleep Disorders* (2nd ed.). Chicago, IL: American Academy of Sleep Medicine. Retrieved from http://www.esst.org/adds/ICSD.pdf

Baker, S. K., & Zee, P. C. (2000). Circadian disorders of the sleep-wake cycle. In: Kryger M. H., Roth T., Dement W. C. (Eds.), *Principles and Practice of Sleep Medicine* (3rd ed.) (pp. 606–614). Philadelphia, PA: Elsevier Saunders.

Belenky, G., Wesensten, N. J., Thorne, D. R., Thomas, M. L., Sing, H. C, Redmond, D. P., Russo, M. B., & Balkin, T. J. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. *Journal of Sleep Research*, *12*(1), 1–12. doi: 10.1046/j.1365-2869.2003.00337.x

Bushnell, P. T., Colombi, A., Caruso, C. C., & Tak, S. (2010). Work schedules and health behavior outcomes at a large manufacturer. *Industrial Health*, *48*, 395–405. Retrieved from https://www.jstage.jst.go.jp/article/indhealth/ 48/4/48_MSSW-03/_pdf

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989a). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research *Psychiatry Research*, *28*(2), 193–213. doi: 10.1016/0165-1781(89)90047-4

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Cajochen, C., Zeitzer, J. M., Czeisler, C. A. Dijk, D. J. (2000). Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human performance. *Behavioral Brain Research*, *115*, 75–83. Retrieved from http://www.chronobiology.ch/wp-content/uploads/publications/2000_12.pdf

Carrier, J., Monk, T. H., Buysse, D. J., & Kupfer, D. J. Sleep and morningness-eveningness in the middle years of life (20–59 years) (1997). *Journal of Sleep Research*, *6*(4), 230–237.

Carskadon M. A., & Dement, W. C. (2005). Normal human sleep: An overview. In: Kryger M. H., Roth T., Dement W. C. (Eds.), *Principles and Practice of Sleep Medicine* (4th ed.) (pp. 13–23). Philadelphia, PA: Elsevier Saunders.

Caruso, C. C. (2014). Negative impacts of shiftwork and long work hours. *Rehabilitation Nursing*, 39(1), 16–25. doi: 10.1002/rnj.107

Chapman, S. L. (2001). The management of stress and fatigue amongst royal Australian submariners (Doctoral dissertation). Royal Australian Navy, Commonwealth of Australia.

Chief of Naval Operations. (2011). *Navy total force manpower policies and procedures* (OPNAV Instruction 1000.16K Change Transmittal 1). Washington, DC: Chief of Naval Operations.

Chiles, J. R. (2002). *Inviting disaster: Lessons from the edge of technology an inside look at catastrophes and why they happen*. New York, NY: HarperCollins Publishers, Inc.

Colten, H. R., & Altevogt, B. M. (Eds.). (2006). *Sleep disorders and sleep deprivation: An unmet public health problem* [Ebrary version]. Retrieved from http://site.ebrary.com/lib/nps/docDetail.action?docID=10146770

Commander, Naval Surface Forces. (2013). *Circadian Watchbill* [Official U.S. Naval Message]. DTG 032157Z May 13. San Diego, CA.

Crick F., Mitchison, G. (1983). The function of dream sleep. *Nature*, *304*(5922), 111–114. Retrieved from http://profiles.nlm.nih.gov/SC/B/C/D/K/_/ scbcdk.pdf

Czeisler, C. A., & Khalsa, S. S. (2000). The human circadian timing system and sleep-wake regulation. In Kryger M. H., Roth T., Dement W. C. (Eds.), *Principles and Practice of Sleep Medicine* (3rd ed.) (pp. 353–376). Philadelphia, PA: Elsevier Saunders.

Czeisler, C. A., Walsh, J. K., Roth, T., Hughes, R. J., Wright, K. P., Kingsbury, L., Arora, S., Schwartz, J. R., Niebler, G. E., Dinges, D. F. (2009). Modafinil for excessive sleepiness associated with shift-work sleep disorder. *The New England Journal of Medicine*, *353*, 476–486. doi: 10.1056/NEJMoa 041292

Czeisler, C. A., Walsh, J.K., Wesnes, K. A., Arora, S., & Roth, T. (2009). Armodafinil for treatment of excessive sleepiness associated with shift work disorder: A randomized controlled study. *Mayo Clinic Proceedings 84*(11), 958–972.

Davenport, N. (2013). Operational stress control: Alternative watch schedule, 3-9 watch rotation. Retrieved from http://www.public.navy.mil/comnav safecen/Documents/video/Sleep-Fatigue/AWS_Summary.pdf

Dawson, D. and Reid, K. (1997). Fatigue, alcohol and performance impairment. *Nature*, *388*(6639), 235–235.

Dement, W. C., & Vaughn, C. (2000). *The promise of sleep: A pioneer in sleep medicine explores the vital connection between health happiness, and a good night's sleep*. New York, NY: Dell Publishing.

Dijk, D. J., & Larkin, W. (2004). Fatigue and performance models: General background and commentary on the circadian alertness simulator for fatigue risk assessment in transportation. *Aviation Space Environmental Medicine*, *75*(3), A119–A121. Retrieved from http://navynps.li brary.ingentaconnect.com/

Dinges, D. F., Connell, L. J., Rosekind, M.R., Gillen, K. A., Kribbs, N. B., & Gracher, R. C. (1991). Effects of cockpit naps and 24-hour layovers on sleep debt in long-haul transmeridian flight crews. *Sleep Research*, *20*, 406.

Dinges, D. F., & Kribbs, N. B. (1991). Performing while sleepy: effects of experimentally-induced sleepiness. In: *Sleep, Sleepiness and Performance*. Timothy H. Monk, ed. Oxford: John Wiley and Sons Ltd: 97–128.

Dinges, D. F., Pack, F., Williams, K., Gillen, K. A., Powell, J. W., Ott, G. E., Aptowicz, C., & Pack, A. I. (1997). Cumulative sleepiness, mood disturbance, and psychomotor performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep*, *20*(4), 267–277.

Dinges, D. F., Whitehouse, W. G., Orne, E. C., & Orne, M. T. (1988). The benefits of a nap during prolonged work and wakefulness. *Work & Stress*, *2*(2), 139–153.

Drake, C. L., Roehrs, T., Richardson, G., Walsh, R. J., & Roth, T. (2004). Shift work sleep disorder: Prevalence and consequences beyond that of symptomatic day workers. *Sleep*, *27*(8), 1453–1462. Retrieved from http://www.journalsleep.org/articles/270801.pdf

Duffy J. F. & Czeisler C. A. (2002). Age-related change in the relationship between circadian period, circadian phase, and diurnal preference in humans. *Neuroscience Letters, 318(3)*, 117–120. doi: 10.1016/S 0304-3940(01)02427-2

Duffy, J. F., Dijk, D. J., Hall, E. F., & Czeisler, C. A. (1999). Relationship of endogenous circadian melatonin and temperature rhythms to self-reported preference for morning or evening activity in young and older people. *Journal of Investigative Medicine, 47*(3), 141–150. Retrieved from http://www.cet.org

Eastman, C. I., Stewart, K. T., Mahoney, M. P., Liu, L., & Fogg, L. F. (1994). Dark goggles and bright light improve circadian rhythm adaptation to night shift work. *Sleep*, *17*(6), 535–543.

Festinger, L. (1962). A theory of cognitive dissonance. Stanford, CA: Stanford University Press.

Folkard, S. &, Akerstedt, T. (1987). Towards a model for the prediction of alertness and/or fatigue on different sleep/wake schedules. In: Oginski, A., Pokorski, J., Rutenfranz, J. (Eds.), *Contemporary advances in shiftwork research* (pp. 231–240) Krakow, Poland: Medical Academy.

Folkard, S., Akerstedt, T. (1992). A three-process model of the regulation of alertness-sleepiness. In: Broughton, R., Wilkinson, R. T., and Ogilvie, R.D. (Eds.), *Arousal and performance: Problems and promises* (pp. 11–26). Boston, MA: Birkenheauser.

Folkard, S., & Lombardi, D. A. (2006). Modeling the impact of the components of long work hours on injuries and "accidents." *American Journal of Industrial Medicine*, *49*(11), 953–963. doi: 10.1002/ajim.20307

Foster, R. G., & Kreitzman, L. (2004). *Rhythms of life: The biological clock that control the daily lives of every living thing*. London: Yale University Press.

Frazier, L. M., & Grainger, D. A. (2003). Shift work and adverse reproductive outcomes among men and women. *Clinics in Occupational and Environmental Medicine*, *3*(2), 279–292.

Gander, P. H., Marshall, N. S., Harris, R., & Reid, P. (2005). The Epworth Sleepiness Scale: Influence of age, ethnicity, and socioeconomic deprivation. Epworth sleepiness scores of adults in New Zealand. *Sleep*, *28*(2), 249–253. Retrieved from http://www.journalsleep.org/ViewAb stract.aspx?pid=26113

Giam, G. K. (1997). Effects of sleep deprivation with reference to military operations. *Annals of the Academy of Medicine Singapore*, *26*(1), 88–93.

Gillette M., Abbott S. (2005). Fundamentals of the circadian system. In: Sleep Research Society, *STS Basics of Sleep Guide* (pp. 131–138). Westchester, IL: Sleep Research Society.

Graeber, R. C., Lauber, J. K., Connell, L. J., & Gander, P. H. (1986). International aircrew sleep and wakefulness after multiple time zone flight: A cooperative study. *Aviation Space and Environment Medicine*, *57* (12 Pt 2), B3–B9.

Green, K. Y. (2009). *A comparative analysis between the navy standard workweek and the actual work/rest patterns of sailors aboard U.S. Navy frigates* (master's thesis). Retrieved from Calhoun http://hdl.handle.net/10 945/4434

Hakola, T., Härmä, M. (2001). Evaluation of a fast forward rotating shift schedule in the steel industry with a special focus on ageing and sleep. *Journal of Human Ergology 30*(1), 315–319.

Härmä M., Hakola, T., Kandolin, I., Sallinon, I., Virkkala, J., Bonnefond, A., Pertti, M. (2006). A controlled intervention study on the effects of a very rapidly forward rotating shift system on sleep-wakefulness and well-being among young and elderly shift workers. *International Journal of Psychology 59*(1), 70–79. doi: 10.1016/j.ijpsycho.2005.08.005

Harma, M., Tenkanen, L., Sjoblom, T., Alikoski, T., & Heinsalmi, P. (1998). Combined effects of shift work and life-style on the prevalence of insomnia, sleep deprivation and daytime sleepiness. *Scandinavian Journal of Work and Environmental Health*, *24*(4), 300–307. doi: 10.5271/sjweh. 324

Haus, E., & Smolensky, M. (2006). Biological clocks and shift work: circadian dysregulation and potential long-term effects. *Cancer Causes and Control*, *17*(4), 489–500. doi: 10.1007/s10552-005-9015-4

Haynes, L. E. (2007). *A comparison between the Navy standard workweek and the actual work and rest patterns of U.S. Navy sailors* (master's thesis). Retrieved from Calhoun http://hdl.handle.net/10945/3298

Hockey, R. (1983). *Stress and fatigue in human performance*. Chichester, NY: Wiley & Sons, Inc.

Hollins, R. N., & Leszczynski, K. M. (2014). *USN manpower determination: A case study using Imprint Pro to validate the core crew manning solution of the Littoral Combat Ship* (master's thesis). Naval Postgraduate School, Monterey, CA.

Hursh, S. R. (2010) Army research psychology: Moving from science to solutions. In *The 71F advantage: applying army research psychology for health and performance gains*. (pp. 47–57). Washington, DC: National Defense University Press.

Hursh, S. R. (2014, May). Qualitative state fatigue model. Presented at Institutes for Behavior Resources, Inc., Baltimore, MD.

Hursh, S. R., Balkin, T. J., Miller, J. C., & Eddy, D. R. (2004). *The fatigue avoidance scheduling tool: Modeling to minimize the effects of fatigue on cognitive performance*. Warrendale, PA: SAE International.

Hursh, S. R., & Bell, G. B. (2001*). Human performance cognitive model for air force information operations*. San Diego, CA: Science Applications International Corporation.

Hursh, S. R., Redmond, D. P., Johnson, M. L., Thorne, D. R., Belenky, G., Balkin, T. J., Storm, W. F., Miller, J. C., & Eddy, D. R. (2004). Fatigue models for applied research in warfighting. *Aviation*, *Space*, *and Environmental Medicine*, *75*(1), A44-A53. Retrieved from https://www.flyawake.org/documents/FatigueModelsPaper.pdf

Institutes for Behavior Resources, Inc. (2014). *SAFTE-FAST: Fatigue modeling for fatigue risk management*. Baltimore, MD: author.

Jewell, A., Wigge, M., Gagnon, C. M., Lynn, L. A., Kirk, K. M., Berg, K. K., … Measell, B. H. (1998). *USS NIMITZ and carrier airwing nine surge demonstration* Vol. I (CRM 97-111). Alexandria, VA: Center for Naval Analyses.

Jewell, A., Wigge, M., Gagnon, C. M., Lynn, L. A., Kirk, K. M., Berg, K. K., … Davenport, N. (1998). *USS NIMITZ and carrier airwing nine surge demonstration Supporting Data (U)* Vol II (CRM 98-79). Alexandria, VA: Center for Naval Analyses.

Jewett, M. E., & Kronauer, R. E. (1999). Interactive mathematical models of subjective alertness and cognitive throughput in humans*. Journal of Biological Rhythms*, *14*(6), 588–597. Retrieved from http://jbr.sagepub.com/content/14/6/588.long

Johns, M. (1991a). A new method for measuring daytime sleepiness: The Epworth Sleepiness Scale. *Sleep, 146*(6), 540–545. Retrieved from http://epworthsleepinessscale.com/wp-content/uploads/2008/12/a-new-method-for-measuring-daytime-sleepiness-the-epworth-sleepiness-scale2.pdf

Johns, M. (1991b). *The Epworth Sleepiness Scale* [Measurement Instrument]. Retrieved from http://web.stanford.edu/~dement/epworth.html

Johnson, J. V., & Lipscomb, J. (2006). Long working hours, occupational health and the changing nature of work organization. *American Journal of Industrial Medicine, 49*, 921–929. doi: 10.1002/ajim.20383

Lamond, N., & Dawson, D. (1999). Quantifying the performance impairment associated with fatigue. *Journal of Sleep Research, 8*(4), 255–262. doi: 10.1046/j.1365-2869.1999.00167.x

Lauderdale, D. S., Knutson, K. L., Yan, L. L., Liu, K., & Rathouz, P. J. (2008). Sleep duration: How well do self-reports reflect objective measures? The CARDIA Sleep Study. *Epidemiology, 19*(6), 838–845. doi: 10.1097/EDE.0b013e318187a7b0

Mason, D. R. (2009). *A comparative analysis between the Navy standard workweek and the work/rest patterns of sailors aboard U.S. Navy cruisers* (master's thesis). Retrieved from Calhoun http://hdl.handle.net/10945/4541

McCallum, M., Sanquist, T., Mitler, M., & Krueger, G. (2003). *Commercial transportation operator fatigue management reference*. U.S. Department of Transportation Research and Special Programs Administration. Retrieved from http://bussafety.fta.dot.gov/uploads/resource/3101_filename

Monk, T. H. (2005). Shift work: Basic principles. In: Kryger M. H., Roth T., Dement W. C. (Eds.), *Principles and Practice of Sleep Medicine* (4th ed.) (pp. 673–679). Philadelphia, PA: Elsevier Saunders.

Moore-Ede, M., Heitmann, A., Guttkuhn, R., Trutschel, U., Aquirre, A., & Croke, D. (2004). Circadian alertness simulator for fatigue risk assessments in transportation: Application to reduce frequency and severity of truck accidents. *Aviation Space Environmental Medicine, 75*(3), A107–A118. Retrieved from http://www.researchgate.net/publication/5337668_Circadian_alertness_simulator_for_fatigue_risk_assessment_in_transportation_application_to_reduce_frequency_and_severity_of_truck_accidents

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Morales, J. D., & Sanchez-Lopez, M. P. (2004). Composite and preferences scales of morningness: Reliability and factor invariance in adult and university samples. *The Spanish Journal of Psychology*, *7*(2), 93–100. doi: 10.1017/S1138741600004790

Naitoh, P., Kelly, T., & Babkoff, H. (1991). *Sleep inertia: Is there a worst time to wake up?* (NHRC 91-45). San Diego, CA: Naval Health Research Center.

National Sleep Foundation (2002). *2002 sleep in America poll* [Brochure]. Retrieved from http://sleepfoundation.org/sites/default/files/2002SleepIn AmericaPoll.pdf

National Sleep Foundation. (2011). Annual sleep in America poll exploring connections with communications technology use and sleep [Press release]. Retrieved from http://www.sleepfoundation.org/article/press-release/annual-sleep-america-poll-exploring-connections-communications-technology-use-

National Sleep Foundation. (2014a). Let sleep work for you. Retrieved from http://sleepfoundation.org/how-sleep-works/let-sleep-work-you/page/0%2C2/

National Sleep Foundation. (2014b). Sleep hygiene. Retrieved from http://sleepfoundation.org/ask-the-expert/sleep-hygiene

National Sleep Foundation. (2014c). White paper: How much sleep do adults need? [Article]. Retrieved from http://sleepfoundation.org/sleep-polls-data/white-papers/how-much-sleep-do-adults-need

National Transportation Safety Board. (1990). *Marine accident report: Grounding of the U.S. tankship Exxon Valdez on Bligh Reef, Prince William Sound Near Valdez, Alaska March 24, 1989* (PB90-916405). Washington, DC: author.

Neri, D. F., Dinges, D. F., & Rosekind, M. R. (1997). *Sustained carrier operations: Sleep loss, performance, and fatigue countermeasures*. Moffett Field, CA: National Aeronautics andSpace Administration, Ames Research Center.

Nguyen, J. L. (2002). *The effects of reversing sleep-wake cycles on sleep and fatigue on the crew of USS John C. Stennis* (master's thesis). Retrieved from http://hdl.handle.net/10945/4736

NTI, Inc. & Science Applications International Corporation. (2012). FAST Version 2.9.04G_T [Computer software]. United States Air Force Contract F41624-99-C-6041.

NTI, Inc. & Science Applications International Corporation. (2012). SAFTE-FAST Version 3.4.0 [Computer Software]. United States Air Force Contract F41624-99-C-6041.

Organization for Economic Co-Operation and Development (2002). *Organization for Economic Co-Operation and Development Outlook*. Paris: OECD.

Ostberg, O. (1973). Interindividual differences in circadian fatigue patterns of shift workers. *British Journal of Industrial Medicine*, *30*(4), 341–351. Retrieved from http://www.ncbi.nlm.nih.gov

Paley, M. J., & Tepas, D. I. (1994). Fatigue and the shiftworker: Firefighters working on a rotating shift schedule. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *36*(2), 269–284. doi: 10.1177/001872089403600208

Paquet J., Kawinska A., & Carrier J. (2007). Wake detection capacity of actigraphy during sleep. *Sleep*, *30*(10), 1362–1369. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2266273/pdf/aasm.30.10.1362.pdf

Philips Respironics. (2009). Twice as easy: Ambulatory actigraphy devices that collect and download continuous, objective long-term sleep/wake data [Brochure]. Retrieved from http://actigraphy.respironics.com/downloads/Actiwatch2_Spectrum.pdf

Philips Respironics. (2013). Respironics Actiware 5 Version 6.0.0 [Computer software]. Murraysville, PA: Philips Respironics.

Pilcher, J. J., Lambert, B. J., & Huffcutt, A. I. (2000). Differential effects of permanent and rotating shifts on self-reported sleep length: A meta-analytic review. *Sleep*, *23*(2), 155–163.

Presser, H. B. (2003). *Working in a 24/7 economy: Challenges for American families*. New York: Russell Sage Foundation.

Purnell, M. T., Feyer, A. M., & Herbison, G. P. (2002). The impact of a nap opportunity during the night shift on the performance and alertness of 12-h shift workers. *Journal of Sleep Research*, *11*(3), 219–227. doi: 10.1046/j.1365-2869.2002.00309.x

R Project for Statistical Computing. (2014). R Version 3.1.0 [Computer software]. Retrieved from http://cran.cnr.berkeley.edu/

Rechtschaffen, A. I., & Bergmann, B. M. (2002). Sleep deprivation in the rat: An update of the 1989 paper. *Sleep*, *25*(1), 18–24.

Roach, G. D., Fletcher, A., & Dawson, D. (2004). A model to predict work-related fatigue based on hours of work. *Aviation Environmental Medicine*, *75*(3), A61–69. Retrieved from http://www.unisanet.unisa.edu.au/staff/matthewthomas/GREG/ roach(model)04.pdf

Roehrs, T., Carskadon, M. A., Dement, W. C., & Roth, T. (2000). Daytime sleepiness and alertness In: Kryger M. H., Roth T., Dement W. C. (Eds.), *Principles and Practice of Sleep Medicine* (3rd ed.) (pp. 43–51). Philadelphia, PA: Elsevier Saunders.

Roenneberg, T., Daan, S., & Merrow, M. (2003). The art of entrainment. *Journal of Biological Rhythms*, *18*(3), 183–184. doi: 10.1177/0748730403018003 001

Roenneberg, T., Justice, A. W., & Merrow, M. (2003). Life between clocks: Daily temporal patterns of human chronotypes. *Journal of Biological Rhythms*, *18*(1), 80–90. doi: 10.1177/0748730402239679

Roenneberg, T., & Kumar, C. J. (2007), The human circadian clock entrains to sun time. *Current Biology 17*(2), R44–R45. doi: http://dx.doi.org/10.1016/ j.cub.2006.12.011

Rosa, R. R., & Colligan, M. J. (1997). *Plain language about shiftwork*. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

Rosekind, M. R., Connell, L. J., Dinges, D. F., Rountree M. S., & Graeber, R. C. (1991). Preplanned cockpit rest: EEG sleep and effects on physiological alertness. *Sleep Research*, *20*, 129.

Rosekind, M. R., Graeber, P. C., Dinges, D. F., Connell, L. J., Rountree, M. S., Spinweber, C. L., & Gillen, K. A., (1994). Crew factors in flight operations, IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations. Technical memorandum 108839. Moffett Field, CA: National Aeronautics and Space Administration, Ames Research Center.

Ross, J. J. (1965). Neurological findings after prolonged sleep deprivation. *Archives of Neurology*, *12*(4), 399–403. doi: 10.1001/archneur.1965.004 60280069006

Sack, R. L. (2010). Jet Lag. *New England Journal of Medicine*, 326, 440–447. Retrieved from http://www.nejm.org/doi/pdf/10.1056/NEJMcp0909838

Schaefer, E. W., Williams, M. V., & Zee, P. C. (2012). Sleep and circadian misalignment for the hospitalist: A review. *Journal of Hospital Medicine*, *7*(6), 489–496. doi: 10.1002/jhm.1903

Schweitzer, P. K., Randazzo, A. C., Stone, K., Erman, M., & Walsh, J. K. (2006). Laboratory and field studies of naps and caffeine as practical countermeasures for sleep-wake problems associated with night work. *Sleep*, *29*(1), 39–50.

Sharkey, K. M., Fogg, L. F., & Eastman, C. I. (2001). Effects of melatonin administration on daytime sleep and simulated night shift work. *Journal of Sleep Research*, *10*(3), 181–192. Retrieved from http://www.ncbi.nlm.nih .gov/pmc/articles/PMC3679650/

Shattuck, N. L., Matsangas, P. (2014). *Psychomotor vigilance performance is predicted by Epworth Sleepiness Scale in an operational setting with the United States Navy*. Manuscript submitted for publication. Operations Research Department, Naval Postgraduate School, Monterey, CA.

Siegel, J. M. (2000). Brainstem mechanisms generating REM sleep. In: Kryger M. H., Roth T., Dement W. C. (Eds.), *Principles and Practice of Sleep Medicine* (3rd ed.) (pp. 112–131). Philadelphia, PA: Elsevier Saunders.

Skinner, S. K., & Reilly, W. K. (1989). *The Exxon Valdez: A report to the president*. Washington, DC: Nation Response Team.

Smith, C. S., & Lapp L. (1991). Increases in number of REMS and REM density in humans following intensive learning period. *Sleep, 14*(4), 325–330.

Smith, C. S., Reilly, C., & Midkiff, K. Evaluation of three circadian rhythm questionnaires with suggestions for an improved measure of morningness (1989). *Journal of Applied Psychology*, *74*(5), 728–738.

Souza, L., Benedito-Silva, A., Pires, M. L., Poyares, D., Tuflik, S., & Calil, H. M. (2007). Further validation of actigraphy for sleep studies. *Sleep*, *26*(1), 81–85.

Stickgold, R., & Walker, M. P. (2007). Sleep-dependent memory consolidation and reconsolidation. *Sleep Medicine*, *8*(4), 331–343. doi:10.1016/j.sleep.20 07.03.011

Tewari, A., Soliz, J., Billota, F., Garg, S., & Singh, H. (2011). Does our sleep affect patients' safety. *Indian Journal of Anesthesia*, *55*(1), 12–17.

U.S. Army Research Laboratory, Human Systems Research and Engineering Directorate. (2010). Improve Performance Research Integration Tool. Retrieved from http://www.arl.army.mil/www/defau lt.cfm?page=445

Van Dongen, P. A. (2004). Comparison of mathematical model predictions to experimental data of fatigue and performance. *Aviation, Space, and Environmental Medicine*, *75*(3), A15–A36. Retrieved from http://faculty.vet.upenn.edu/uep/user_documents/Van_Dongen_ASEM_75 _3_2004.pdf

Van Dongen, H. P., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavorial functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, *27*(2), 117–126. Retrieved from https://www.med.upenn.edu/uep/user_documents/Van Dongen_etal_Sleep_26_2_2003.pdf

Van Dongen, H. P., Rogers, N., & Dinges, D. F. (2003). Sleep debt: Theoretical and empirical issues. *Sleep and Biological Rhythms*, *1*(1), 5–13. doi: 10.1046 /j.1446-9235.2003.00006.x

Winget C. M., DeRoshia, C. W., & Holley, D. C. (1985). Circadian rhythms and athletic performance. *Medicine and Science in Sports and Exercise*, *17*(5), 498–516.

Wright, K. P., McHill, A. W., Birks, B. R., Griffin, B. R, Rusterholz, T., & Chinoy, E. D. (2013). Entrainment of the human circadian clock to the natural light-dark cycle. *Current Biology*, *23*(16), 1554–1558. doi: 10.1016/j.cub.2013 .06.039

Xie, L., Kang, H., Xu, Q., Chen, M. J., Liao, Y., Thiyagarajan, M., O'Donnell, J., Christensen, D. J., Nicholson, C., Iliff, J. J., Takano, T., Deane, R., & Nedergaard, M. (2013). Sleep drives metabolite clearance from the adult brain. *Science*, *342*(6165), 373–377. doi: 10.1126/science.1241224

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